

**Development of the University of Canterbury
Paediatric Auditory-Visual Matrix Sentence Test:
Sentence Equivalence and Normative Data**

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For Dad

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Abstract

Communication is an important aspect of our ability to learn, interact with those around us, and participate successfully as a member of society (Tye-Murray, 2009). The ability to hear underlies communication, and thus identification of hearing impairment is highly important (Neumann et al., 2012). A battery of audiological tests is commonly used to identify and quantify hearing impairment; an important component of this is speech recognition testing. The University of Canterbury Auditory-Visual Matrix Sentence Test - Paediatric Version (UCAMST-P) was developed with the aim of adding a speech recognition test to the current audiological test battery used with paediatric populations in New Zealand, and was assessed with adult populations (Jenkins-Foreman, 2018). In this study, the UCAMST-P was piloted with children from six to 12 years of age with normal hearing. New sentence lists were also generated with the aim of improving equivalence of sentence list stimuli, and these were used in this study. The effect of age, ear tested, gender, household income, ethnicity, developmental factors, and academic achievement on UCAMST-P performance for this cohort of children was also investigated. Speech recognition threshold (SRT) scores were found to improve with age up to approximately 10 years, and then plateau for the remaining age groups. Sentence list equivalence was unable to be assessed statistically, but the sentence lists generated in this study varied less with regards to SRT scores than that used previously, as indicated by a smaller standard deviation. Co-variables were found to have no effect on UCAMST-P performance. The data collected in this study contributes towards the development of the UCAMST-P, increasing the feasibility of its future use in the paediatric audiological test battery in New Zealand.

Table of Contents

Acknowledgements	ii
Abstract.....	iii
Table of Contents	iv
List of Tables	vii
List of Figures.....	viii
List of Abbreviations	x
1 Introduction.....	1
1.1 Sound and Hearing.....	1
1.1.1 The auditory system.....	1
1.1.2 Cochlear mechanics.	2
1.2 Central processing of sound	4
1.2.1 Understanding speech.	4
1.2.2 Hearing impairment.	5
1.3 Audiological Assessment.....	6
1.3.1 Identifying hearing impairment.	6
1.3.2 Current audiological test battery in New Zealand.	6
1.3.3 Paediatric audiological assessment.	7
1.4 Speech recognition testing	8
1.4.1 Overview.....	8
1.4.2 Administration of speech recognition tests.....	9
1.4.3 Measures of speech perception.	13
1.5 Speech Perception Tests Using Word Stimuli	16
1.6 Paediatric Speech Audiology	17
1.6.1 Requirements for paediatric speech perception tests.	17
1.6.2 Existing paediatric speech perception tests.....	18
1.7 Paediatric speech testing in New Zealand.....	20
1.7.1 Current practice in New Zealand.	20
1.7.2 The Kendall Toy Test.	21
1.8 A New Zealand Matrix Sentence Test	22
1.8.1 The University of Canterbury Audio-Visual Matrix Sentence Test (UCAMST). 22	
1.8.2 UCAMST-P: Paediatric version.	24
1.8.3 List equivalence.	24
1.8.4 SRT tracking procedure.	25
1.9 Current study.....	26
1.9.1 Rationale for current project.	26
1.9.2 Aims.....	27

1.9.3	Research questions.....	27
1.9.4	Hypotheses.....	28
2	Methods.....	29
2.1	Overview.....	29
2.2	Participants.....	29
2.2.1	Recruitment.....	29
2.2.2	Inclusion criteria.	30
2.3	Equipment.....	31
2.3.1	Overview.....	31
2.3.2	Equipment used with participants from the “Learning to Talk” Database.	31
2.3.3	Equipment used for testing participants from primary schools and the music school. 32	
2.4	Stimuli.....	32
2.4.1	Generation of new sentence lists.....	32
2.4.2	Stimuli number.....	33
2.5	Experimental Procedures.....	33
2.5.1	Conditions in which the UCAMST-P was administered.	35
2.5.2	Operation of the UCAMST-P.	35
2.6	Measures.....	36
2.6.1	Scoring procedures.....	36
2.6.2	SRT measurement.....	36
2.7	Planned statistical analyses	37
3	Results.....	38
3.1	Participants.....	38
3.2	Separate Ear Results.....	39
3.2.1	Right ear.....	40
3.2.2	Left ear.....	41
3.3	Combined Ear Results.....	42
3.3.1	Co-variates.	44
3.4	Gender Effect	47
3.5	Ear Effect.....	49
3.6	Sentence List Equivalence	50
4	Discussion	51
4.1	Introduction.....	51
4.2	Main Effects of Age, Ear, and Gender.....	51
4.2.1	Age Effect.	51
4.2.2	Ear effect.....	53
4.2.3	Gender Effect.	54

4.3	Co-variates	55
4.4	Study Limitations and Future Research	55
4.4.1	Sample size.	56
4.4.2	Recruitment.....	56
4.4.3	Inter-tester reliability.	56
4.4.4	School testing conditions.	57
4.5	Future Research.....	57
4.5.1	Sentence list equivalence.	58
4.5.2	Conditions in which UCAMST-P is administered.....	58
4.5.3	Piloting with younger age groups.	59
4.5.4	Piloting with children with hearing impairment.	59
4.6	Concluding Remarks	59
References.....		61
Appendices.....		75
A.	Ethical Approval.....	76
B.	Information Documentation	78
C.	Consent Forms.....	90
D.	Assent Forms	93
E.	Questionnaires	95
F.	Sentence Lists	97
G.	Hearing Screen Result Sheets.....	98

List of Tables

Table 1: Age-specific mean SRT with standard deviation (SD), upper and lower bounds of 95% confidence interval, and median SRT with 90th and 10th percentiles. N_{total} = total number of participants, N_{valid} = number of participants who passed the hearing screen in the respective ear, RE = right ear, LE = left ear.	39
Table 2: Post-hoc pairwise comparisons in right ear SRT using the LSD correction.	41
Table 3: Post-hoc pairwise comparisons in left ear SRT using the LSD correction.....	42
Table 4: Post-hoc pairwise comparisons in combined SRT using the LSD correction.	44

List of Figures

Figure 1 Two example psychometric functions with different slopes. The blue solid curve represents a function with a shallower slope, and the green dashed curve represents a function with a steeper slope.....	15
Figure 2 Example PI function.....	20
Figure 3: Matrix of words used in the UCAMST-P.	36
Figure 4: Boxplots of SRT measures for the right ear only, across the six age groups. Only the SRT measures of participants who passed the hearing screen with the right ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparison using least significant differences [LSD] correction).....	40
Figure 5: Boxplots of SRT measures for the left ear only, across the six age groups. Only the SRT measures of participants who passed the hearing screen with the left ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparison using LSD correction).	41
Figure 6: Boxplots of combined SRTs, calculated from the average of the left and right ear SRTs, across the six age groups. Only the SRT measures of participants who passed the hearing screen with at least one ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparisons using the LSD correction).	43
Figure 7: Boxplots of age-specific combined SRTs of participants who currently and have always met the reading curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the reading curriculum standard (“Below”). Significant outliers indicated by asterisks, non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.....	45
Figure 8: Boxplots of age-specific combined SRTs of participants who currently and have always met the writing curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the writing curriculum standard (“Below”). Significant outliers indicated by asterisks, non-significant outliers indicated by circles.....	45
Figure 9: Boxplots of age-specific combined SRTs of participants who currently and have always met the language curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the language curriculum standard (“Below”). Significant outliers indicated by asterisks, non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.....	46
Figure 10: Boxplots of age-specific combined SRTs of participants who currently and have always met the behaviour curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the behaviour curriculum standard (“Below”). Non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.....	46
Figure 11: Boxplots of age-specific combined SRTs of participants with reported typical and non-typical developmental history. Non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.	47
Figure 12: Boxplots of right ear SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with the right ear were	

included in this graph. Significant outliers indicated by asterisks, non-significant outliers indicated by circles.	48
Figure 13: Boxplots of left ear SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with the left ear were included in this graph. Non-significant outliers indicated by circles.....	48
Figure 14: Boxplots of combined SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with at least one ear were included in this graph. Significant outliers indicated by asterisks, non-significant outliers indicated by circles.	49
Figure 15: Boxplots of right and left ear SRTs for each age group. Non-significant outliers indicated by circles.	50

List of Abbreviations

AA	Auditory-alone
ANOVA	Analysis of variance
ANT	Auditory Numbers Test
AV	Audio-visual
BKB-SIN	Bamford-Kowal-Bench Speech-in-Noise test
BM	Basilar membrane
BOA	Behavioural observation audiometry
CRISP	Children's Realistic Inventory of Speech Perception
CRISP Jr.	Children's Realistic Inventory of Speech Perception Junior
CVC	Consonant-Vowel-Consonant
dB	Decibel
dB HL	Decibels in hearing level
dB SNR	Decibels in signal-to-noise ratio
dB SPL	Decibels in sound pressure level
ESP	Early Speech Perception test
HI	Hearing impairment
HINT	Hearing in Noise Test
IHC	Inner hair cell
KTT	Kendall Toy Test
LSD	Least significant differences
MLV	Monitored Live Voice
MOH	Ministry of Health
MST	Matrix Sentence Test
NU-CHIPS	Northwestern University Children's Hearing in Pictures
NZ	New Zealand

NZAS	New Zealand Audiological Society
NZILBB	New Zealand Institute of Language Brain and Behaviour
OAE	Otoacoustic emission
OHC	Outer hair cell
OlSa	Oldenburger Satztest (Oldenburg Sentence Test)
OLKiSa	Oldenburger Kinder-Satztest for younger children (Oldenburg Sentence Test for Children)
PI	Performance-intensity function
PPMST	Polish Paediatric Matrix Sentence Test
PSI	Paediatric Speech Intelligibility
PTA	Pure tone audiometry
QuickSIN	Quick Speech-in-Noise test
SD	Standard deviation
SLM	Sound level meter
SNR	Signal-to-noise ratio
SRT	Speech recognition threshold
UCAMST	University of Canterbury Auditory-Visual Matrix Sentence Test
UCAMST-P	University of Canterbury Auditory-Visual Matrix Sentence Test – Paediatric Version
UCAST-FW	University of Canterbury Adaptive Speech Test – Filtered Words
UNHSEIP	New Zealand Universal Neonatal Hearing Screening and Early Intervention Programme
VA	Visual-alone
VRA	Visual reinforcement audiometry

1 Introduction

1.1 Sound and Hearing

The world that we live in is a noisy one. We navigate a complex array of sounds every day, from which our brains extract information most important to us (Lesicko & Llano, 2017; Purves, 2004). Our ability to communicate with our peers, and our appreciation of music, is usually dependent on our ability to process sound. Processing auditory stimuli is an intricate process requiring us first to sense sound, a bottom-up process, and then process this information via complex neural networks within the brain, a top-down process (Purves, 2004).

1.1.1 The auditory system.

Transducing, encoding, and perceiving information from external and internal environmental stimuli allows us to hear, touch, see, taste, and smell (Glickstein, 2014; Purves, 2004). Stimulus energy is detected by receptor cells, encoded as neural signals, and transmitted to the brain for processing (Purves, 2004). Qualitative and quantitative aspects of the stimulus, including in some modalities its localisation, can be encoded by neurons involved in the transmission of stimuli to the brain (Purves, 2004).

The auditory system is responsible for detecting and processing information about sound stimuli. Sound consists of longitudinal waves generated by vibrating molecules of the surrounding medium. These waves are collected by the outer ear, which consists of the pinna, concha, and auditory meatus, and focused onto the eardrum. Behind this lie the ossicles of the middle ear: the malleus, incus, and stapes. The mechanical energy of the eardrum is transferred via the ossicles to the cochlea of the inner ear. At the cochlea, mechanical energy is transduced by hair cells and converted into electrical energy, and transmitted as nerve

impulses to the brain for processing, via the eighth nerve and ascending auditory pathways (Hoit, 2016; Purves, 2004).

1.1.2 Cochlear mechanics.

The cochlea is a spiral-like structure divided along its length by two membranes, the basilar membrane (BM) and Reissner's membrane. Incompressible fluids are contained within the bony rigid walls of the cochlea. Sound arriving at the cochlea displaces the cochlear fluid, creating a pattern of vibration that moves along the BM from the start of the cochlea, termed the base, to the inner tip, termed the apex (Moore, 2013). Sinusoidal stimulation takes the form of a "travelling wave" that increases towards a peak amplitude at a particular point on the BM, then decreases in amplitude as it travels further towards the apical end (Békésy, 1947; Moore, 2013; Ren, 2002).

Each travelling wave displaces the BM maximally at different positions due to the mechanical properties of the BM. The apex of the cochlea is wider and less stiff than the basal end, resulting in a position of maximal displacement according to the frequency of stimulation (Moore, 2013). Low frequency sounds create a pattern of vibration that travels along the BM before displacing the membrane maximally at a position closer to the apical end. High frequency sounds produce maximum displacement near the basal end, and produce little movement on the remainder of the BM (Moore, 2013). The ability of the BM to respond differently to sinusoidal stimuli of various frequencies allows the analysis of complex sound stimuli into its component frequencies.

A third membrane, the tectorial membrane, lies between the BM and Reissner's membrane. Hair cells are found between the BM and tectorial membrane, of which there are two classes that differ in anatomy and functionality: inner hair cells (IHCs) and outer hair

cells (OHCs) (Moore, 2013). The IHCs form a single row at the basal pole, whereas the OHCs lie in three to four rows at the apical pole (Ashmore, 2008). Thousands of tiny hair-like projections, called stereocilia, are found atop both groups of hair cells; OHC stereocilia appear to make contact with the tectorial membrane but it is unsure whether IHC stereocilia do (Moore, 2013). The tectorial membrane has a gelatinous structure and is effectively hinged at one side, which causes a radial shear force between the BM and tectorial membrane when BM movement occurs (Moore, 2013).

The OHCs appear to play an active role in ensuring high sensitivity and sharp tuning of the cochlea. The exact mechanism by which these active processes produce high sensitivity and sharp tuning is still unclear (Ashmore, 2008; Moore, 2013). The present consensus is that when a travelling wave arrives, OHC stereocilia are deflected due to the radial shear force caused by the travelling wave. Transduction channels on the stereocilia open, allowing flow of potassium ions into OHCs (Moore, 2013). Subsequent depolarisation of these cells causes a somatic motor protein, prestin, to contract and elongate, resulting in OHC movement. This feeds energy back into the travelling wave, thereby cancelling the dampening of the wave caused by the surrounding fluid viscosity and increasing wave amplitude (Ashmore, 2008; Parbery-Clark, Skoe, Lam, & Kraus, 2009).

IHCs transduce mechanical movements of the BM into electrical signals, which are carried down the auditory nerve to higher brain centres (Ashmore, 2008; Moore, 2013). The mechanism underlying this is similar to that of OHCs. When a travelling wave arrives, IHC stereocilia are deflected by BM movement, allowing cation-transducing channels to open. Potassium ions flow into the IHCs, causing depolarisation and subsequent release of neurotransmitter (Moore, 2013). Action potentials are initiated in neurons of the auditory nerve, transmitting information to higher levels of the auditory system (Moore, 2013).

1.2 Central processing of sound

Once information has been extracted from the external environment via the peripheral auditory system, it is then transmitted to higher auditory centres and processed within the brain. Information from both ears are integrated, meaning is assigned, and responsive actions are initiated. Processing auditory stimuli allows for environmental awareness, localisation of sound, and making sense of speech (Obleser, 2014).

1.2.1 Understanding speech.

The ability to hear and understand speech allows communication, and the establishment and maintenance of relationships with peers to occur (Habanec & Kelly-Campbell, 2015; Katz, Chasin, English, Hood, & Tillery, 2015). Hearing not only plays a vital role in communication, but in the development of oral language, behaviour, and academic ability in children (Shojaei, Jafari, & Gholami, 2016). Speech can be a multimodal signal, consisting of visual speaker articulations and auditory cues. To recognise speech, audiovisual (AV) processing of detailed spectro-temporal information must be combined with robust central pattern recognition (Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000).

The cochlea plays an important role in our ability to perceive speech and extract important signals from background noise (Mesgarani, David, Fritz, & Shamma, 2014). The ability of the cochlea to resolve the sinusoidal components of sound and its high sensitivity and sharp tuning characteristics allow the perception of loudness, pitch, timbre, and meaning (Moore, 2008). For example, evaluation of a word into its component frequencies allows the mapping of components of the word to phonemic categories, and subsequent mapping of phonemes to meaning (Wong et al., 2009).

1.2.2 Hearing impairment.

Hearing impairment (HI) can be due to the abnormality of one or many structures detailed above that form the auditory system. HI decreases a listener's access to sound, and may have far-reaching effects on the opportunities available to the individual. Development, communication, education, and the ability to participate successfully as a member of society can be negatively impacted (Shojaei et al., 2016; Tye-Murray, 2009). Unmanaged HI may also reduce an individual's independence and emotional well-being, resulting in withdrawal and social isolation (Kelly-Campbell, Thomas, & McMillan, 2015). The potential impact of HI on an individual's development, communication, cognitive functioning, and psychosocial functioning makes clear the importance of identifying and managing HI (Habanec & Kelly-Campbell, 2015).

Damage to the cochlea commonly underlies hearing loss. Damage to OHCs within the cochlea leads to reduced frequency discrimination and sharp tuning. This results in "blurred" excitation patterns of complex sounds and difficulty distinguishing different timbres of vowel sounds (Moore, 2008). When hearing speech in background noise, the same location on the BM is stimulated by the signal of interest and noise of corresponding frequency. Noise within a region of frequencies near the signal frequency can "mask out" the signal being perceived, if the noise intensity is high enough (Moore, 2013). The range of frequencies which can mask out the signal of interest is larger in people with HI than those with normal hearing due to a reduction in frequency discrimination. As a result, those with HI have a greater susceptibility to masking of speech by background noise (Moore, 2008). IHC damage prevents the transduction of mechanical energy representing sounds into electrical impulses in the auditory nerve. Consequently, coding of loudness and frequency is disrupted (Moore, 2013). Thus, individuals with HI commonly perceive a speech signal that is less audible and more

distorted than that of their normal hearing peers, an effect that is magnified in the presence of background noise.

1.3 Audiological Assessment

1.3.1 Identifying hearing impairment.

Identification of HI through reliable audiometric testing and appropriate intervention can positively address the impact of decreased hearing ability (Neumann et al., 2012; Shojaei et al., 2016). To assess the functional integrity of separate levels of the auditory system a battery of different audiological tests are required. Distinctive tests can provide information on the presence and nature of an auditory deficit, or the site of a lesion within the auditory system causing HI. Differential information such as this can be vital in determining the course of management most beneficial to the patient or client. In addition, the results of certain audiological tests can cross-check results of other tests within the audiological test battery (Jerger & Hayes, 1976; Katz et al., 2015).

1.3.2 Current audiological test battery in New Zealand.

The current test battery recommended by the New Zealand Audiological Society (NZAS) includes tympanometry, pure tone audiometry (PTA) (consisting of air conduction and bone conduction testing), speech audiometry, acoustic reflexes, and otoacoustic emissions (OAEs) (New Zealand Audiological Society, 2015). Air conduction pure tone audiometry uses tonal stimuli to assess functionality of the auditory system as a whole. Bone conduction bypasses the outer and middle ear components and stimulates the inner ear directly (Katz et al., 2015). Speech recognition tests assess the listener's ability to perceive speech stimuli in quiet or in background noise. The response of the middle ear to sound is measured with tympanometry. Acoustic reflexes also measure this, differentiating middle ear, cochlear, retrocochlear and non-auditory sites of lesions, in conjunction with other test results

(Katz et al., 2015). OAEs result from energy generated in the cochlea in response to the presentation of acoustic stimuli propagated through the middle and outer ears, and are used to screen for HI greater than a mild loss (Katz et al., 2015). Acoustic reflexes, tympanometry and OAEs can cross-check pure tone audiometry results and reinforce the diagnosis of the conductive element of a hearing loss (Katz et al., 2015).

1.3.3 Paediatric audiological assessment.

When assessing a child's hearing, the diagnostic outcomes sought vary little from an adult's (Diefendorf & Wynne, 2004). A test battery approach is recommended, just as it is with adults, to provide optimum information about site of lesion causing HI and assist in determining the best pathway for auditory rehabilitation. The needs of children with HI, and their families, differ substantially from those of their adult counterparts (New Zealand Audiological Society, 2008). Using a battery of tests, with variations in PTA and speech testing, helps to account for age, physical and cognitive conditions, and presence of multiple disabilities (Diefendorf & Wynne, 2004; New Zealand Audiological Society, 2015).

NZAS' clinical standards specify the same types of diagnostic tests in their paediatric audiological test battery as for an adult, but the administration of PTA and speech tests vary depending on the age of the child. PTA can be administered via behavioural observation (BOA), visual reinforcement audiometry (VRA), or play audiometry (New Zealand Audiological Society, 2015). BOA is most suitable for infants up to six months of age as only a change in behaviour is required, whereas VRA requires a head turn response, so is most suitable for infants from approximately five to 36 months. Lastly, play audiometry is generally best for children older than two and a half years, as it requires an active response to be conditioned during the test (Madell & Flexer, 2014). The variation in these tests

demonstrates the importance of administering tests most suitable to the age, developmental stage, and physical and cognitive limits of the individual child.

1.4 Speech recognition testing

1.4.1 Overview.

Speech recognition tests are an important component of the audiological test battery as they provide a real-world measure of auditory function, indicative of an individual's ability to hear and perceive different speech sounds at suprathreshold levels (Katz et al., 2015; Mendel, 2008). The ability of an individual to understand speech may be greater or less than that indicated by the pure tone audiogram (Dietz et al., 2014). Speech audiometry assesses the audibility component, the loss of a listener's sensitivity for speech, in addition to the distortion component, the loss of clarity when speech is heard (Katz et al., 2015; Plomp, 1978).

Examining speech processing abilities throughout the auditory system is useful in determining how well a child functions with and without technology, and in quiet or background noise (Madell & Flexer, 2014; Mendel, 2008). Ongoing testing ensures the ability to monitor a child's developmental progress and alter amplification and intervention efforts if required (Mendel, 2008). Because speech perception is an abstract construct rather than a concrete entity, a test battery approach is needed to provide a comprehensive assessment of a child's abilities, as it provides several sources of concrete data (Mendel, 2008).

There are several aspects of consideration when designing a speech perception test, and different modalities in which the test can be administered. The type of speech stimuli, the way in which it is presented, and if a test is presented in quiet or in background noise can

determine what aspects of hearing ability are examined; the exact conditions and presentation of stimuli used depends on the aim of the assessment, and the age and developmental stage of the child. In addition, the measure used to assess speech perception ability varies between each case. Such aspects are described in the following sections.

1.4.2 Administration of speech recognition tests.

1.4.2.1 Speech stimuli type.

Stimuli used in speech perception testing include syllables, digits, words, and sentences (Dietz et al., 2014). Speech perception in English is commonly assessed using monosyllabic words as stimuli presented in quiet or background noise. The number of phonemes or words correctly identified can be used as an indicator of speech perception ability.

Phoneme testing provides the fewest cues and is less redundant than other stimuli scoring methods, and is therefore the most difficult (Madell & Flexer, 2014). However, it is a valuable method as it indicates exactly what the individual perceives (Madell & Flexer, 2014). Word stimuli presented in isolation tests audibility without confounding factors like working memory or the use of contextual clues (Wilson, McArdle, and Smith, 2007). The listener's familiarity or non-familiarity with the word may, however, affect the accuracy of testing. Carrier phrases such as "show me the" or "where is the" alerts the listener to attend, and places word stimuli in sentence context, more accurately representing its use in normal conversation (Madell & Flexer, 2014). Most word recognition tasks were designed to be used with carrier phrases.

Using natural sentence stimuli allows a listener to extrapolate words from contextual cues if they have not correctly perceived them, providing a less accurate measure of speech

perception (Madell & Flexer, 2014). In addition, the listener is required to retain the test stimuli in their short-term auditory memory for the length of the sentence before reporting the words heard. This adds to the cognitive load of each trial, which in turn impacts the accuracy with which speech perception is measured (Theunissen, Swanepoel, & Hanekom, 2009). Even so, sentence stimuli may afford a better estimate of a listener's communication difficulties. Doubling the number of words in a sentence list increases the precision of a speech-audiometric test by $\sqrt{2}$ (Hagerman, 1976). In addition, a greater number of speech sounds being tested within a solitary trial enhances the time-efficiency with which speech perception is assessed (Hochmuth et al., 2012). Sentence stimuli provide tests more representative of realistic communication situations than that provided by words or syllables alone (Dietz et al., 2014).

1.4.2.2 Closed-set versus open-set.

The “response mode” of a test refers to whether it is “closed-set” or “open-set”. In closed-set testing, the listener points to, or otherwise indicates, one of a restricted number of possible items that may be numbers, body parts, pictures, or alphabet letters (Madell & Flexer, 2014). Different to this, open-set testing offers no clues and requires the listener to repeat what they have just heard (Madell & Flexer, 2014). Lower scores often result from open-set testing due to the greater difficulty of open-set testing over closed-set testing (Madell & Flexer, 2014). Open-set testing, however, more realistically represents speech perception capabilities in conversation, and should be used as soon as a child is capable of the task (Madell & Flexer, 2014).

1.4.2.3 Speech stimulus presentation.

Speech stimuli can be administered via monitored live voice (MLV) or a recording (Madell & Flexer, 2014). MLV has the advantage of allowing the audiologist to make adaptations as required. For example, a listener may need relatively more encouragement, which requires more time between stimuli than a fixed CD or tape recording permits (Madell & Flexer, 2014). Using the pause button of a CD player may be difficult and requires experience (Madell & Flexer, 2014), but such difficulties can now be easily overcome with computer-based delivery of the recordings. MLV may be disadvantageous as prior research has shown overestimation of a child's speech recognition abilities due to familiarity effects of the speaker (Madell & Flexer, 2014). A recording is advantageous in that it provides a more accurate representation of the listener's auditory performance, as it is easily comparable between test sessions and audiologists (Madell & Flexer, 2014).

1.4.2.4 Speech in quiet versus speech in background noise.

Speech perception tests can be administered in quiet, or in the presence of pre-recorded background noise. Speech recognition abilities in quiet assesses the audibility component of hearing loss whereas speech perception tests run in background noise typically quantify the distortion component of the loss (Katz et al., 2015). When attempting to recognise speech in the presence of background noise, adults with HI perform poorer than those with normal hearing (Festen & Plomp, 1990; Hagerman, 2002). Noise limits a listener's access to acoustic-phonetic cues, which are used to recognize verbal information. HI further limits access to these cues, making it more difficult to understand speech in adverse listening environments (Ng, Meston, Scollie, & Seewald, 2011).

Children have greater difficulty correctly recognising speech in noisy or reverberant environments than adults, which is further exacerbated by hearing loss (Nabelek & Pickett,

1974; Ng et al., 2011). As children are still acquiring language, they are less able than adults to use contextual cues, making speech perception more difficult in noise. Cognitive factors, such as attention, memory, and fatigue may also negatively impact perception during difficult listening tasks (Lewis, Hoover, Choi, & Stelmachowicz, 2010). This is an important point of consideration, as noise and reverberation levels in typical classroom environments are greater than what is optimal for a child's learning (Bradley, 1986).

Speech perception tests presented in quiet assess how well a listener can understand speech at different intensity levels in a quiet environment (Katz et al., 2015). In cases of severe HI, specific language impairment, multilingual children, or because it may be the only method available, a test of speech perception in quiet may be more suitable than that in noise (Neumann et al., 2012). However, measuring speech recognition in quiet alone insufficiently establishes the communication difficulties that individuals have in everyday life, particularly in background noise (Beattie, Barr, & Roup, 1997; Carhart & Tillman, 1970). Due to the simplicity of such tests, the sensitivity with which they can distinguish between individuals with normal hearing and individuals with mild HI is of concern (Beattie et al., 1997). Measures of speech recognition that employ background noise afford a more realistic measure of a listener's ability to communicate in real-world situations (Ng et al., 2011). Such information enables the clinician to create a management plan that addresses the listener's ability, and impart realistic expectations when counselling on the benefits and shortfalls of various management approaches (Wilson, McArdle, & Smith, 2007).

Even though there are many advantages of speech-in-noise testing over speech-in-quiet tests, there is a paucity of speech-in-noise testing within the clinical environment. Clinicians are more familiar with speech perception testing that present monosyllabic words in quiet and the percent scoring method involved, as opposed to a signal-to-noise ratio (SNR)

hearing loss measure (Wilson et al., 2007). Clinicians may be unsure of how to tailor counselling and a rehabilitation plan to a SNR hearing loss (Wilson et al., 2007). A lack of normative data within and across speech-in-noise tests may also contribute to the lack of use of speech-in-noise tests in the clinical environment (Wilson et al., 2007).

1.4.2.5 Response tasks.

Four response tasks used to assess performance on speech perception tests are detection, discrimination, identification, and comprehension (Madell & Flexer, 2014). Threshold tests assess the ability to tell when a stimulus is present, termed detection. Discrimination is the ability to recognise if two stimuli are the same or different. Identification is demonstrated by repeating or pointing to a stimulus, or writing the stimulus recognised. Lastly, comprehension is the ability to understand what a stimulus means (Madell & Flexer, 2014). Different response tasks provide different information about a listener's speech perception ability.

1.4.3 Measures of speech perception.

1.4.3.1 Speech recognition threshold and psychometric function slope values.

A number of tests measure percent intelligibility, the percentage of correct responses, at fixed speech and/or noise levels (Nilsson, Soli, & Sullivan, 1994). Percent intelligibility scores reliably estimate performance, but are subject to floor and ceiling effects (Nilsson et al., 1994). Alternatively, performance on speech perception tests are specified via speech recognition threshold (SRT) values. When measured in decibels, SRT scores quantify the sound pressure level at which 50% of the presented words are correctly identified (Boothroyd, 2008). A more negative SRT score indicates better speech recognition performance. The average of air conduction thresholds at 0.5, 1, and 2 kHz, known as a pure

tone average, should correspond with the SRT in the same ear (Boothroyd, 2008; Katz et al., 2015).

With testing conducted in noise, the SRT is derived from a psychometric function depicting the percentage of correct responses as a function of the SNR. In this case, SRT is a dB SNR measure and quantifies the signal-to-noise ratio required to correctly identify a certain proportion of presented words. In order to differentiate between different acoustical situations and individuals, standard deviation of the SRT should be less than 1 dB between sentence lists and repeated measures employed (Brand & Kollmeier, 2002). The slope of the psychometric function measures the proportional rate of change in performance in response to variations in the level of the stimulus, and represents accuracy of the SRT measure (Neumann et al., 2012; Ozimek et al., 2010). The relationship between slope and accuracy of SRT measure is an orthodox inverse one; as slope increases, the standard deviation (SD) of the SRT decreases (Ozimek et al., 2010). Sentence stimuli produce discrimination functions with considerably steeper slopes than word stimuli, and thus more accurately measure SRT (Brand & Kollmeier, 2002).

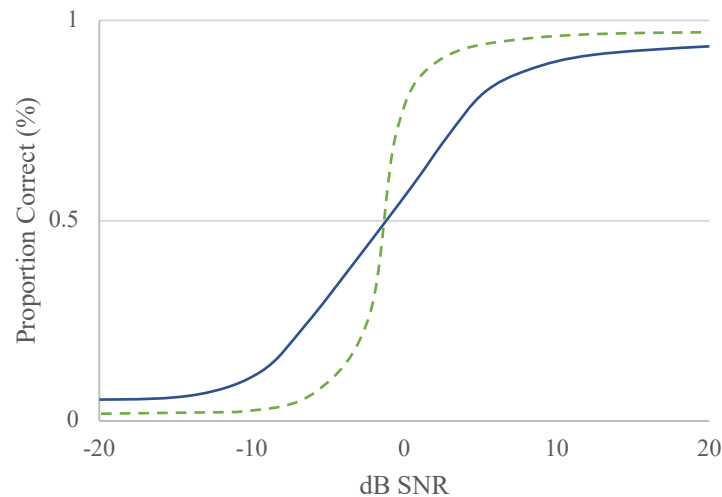


Figure 1 Two example psychometric functions with different slopes. The blue solid curve represents a function with a shallower slope, and the green dashed curve represents a function with a steeper slope.

1.4.3.2 SNR tracking procedure.

Speech perception can be tested using adaptive or non-adaptive procedures. Non-adaptive procedures involve measuring percentage intelligibility at a fixed SNR level. The SNR of stimuli is established prior to testing by the clinician, and remains the same throughout (Taylor, 2003). With a non-adaptive procedure, Levitt and Rabiner (1967) found that speech intelligibility curves tend to flatten at relatively high intelligibility levels i.e. 100% intelligibility is never achieved. To address this issue, an adaptive procedure was suggested in which SNR is decreased by a fixed amount if a correct response is given or increased by the same fixed amount if the listener incorrectly identifies the stimuli (Levitt & Rabiner, 1967). As the test progresses, the SNR converges on the level at which some proportion (e.g. 50%) of stimuli are correctly identified (Levitt & Rabiner, 1967). Adaptive procedures allow SNR presentation levels to be concentrated in the range which yields SRT and slope estimates with the smallest standard deviations (Brand & Kollmeier, 2002).

The slope measurement of a psychometric function is based on the level at which 50% intelligibility is demonstrated, however, intelligibility beyond about 80% is more relevant to

a listener's ability to communicate in noise (Brand & Kollmeier, 2002). Brand and Kollmeier (2002) trialled an alternative procedure which allowed concurrent estimates of SRT and slope within a tolerable measuring time. This adaptive procedure converges at the pair of compromise, which are the target levels allowing most efficient estimates of concurrent threshold and psychometric slope (Brand & Kollmeier, 2002). The pair of compromise typically correspond to the 20% and 80% correct points. The psychometric function is extrapolated between these two points, and measurement of the slope at the 50% correct point can indicate accuracy of the SRT measure.

1.5 Speech Perception Tests Using Word Stimuli

Two types of sentence tests are commonly used to assess speech perception (Dietz et al., 2014). One type of test uses meaningful, phonemically-balanced everyday sentences without grammatical structure as stimuli, such as that proposed by Plomp and Mimpen, termed "Plomp-type" sentences (Dietz et al., 2014; Nilsson et al., 1994; Plomp & Mimpen, 1979; Theunissen, Swanepoel, & Hanekom, 2009). A second type of sentence test, matrix sentence tests (MSTs), use sentence stimuli consisting of a name, verb, number, adjective, object structure, in background noise, to form syntactically fixed but semantically unpredictable sentences. Sentences are formed by words chosen from a matrix of pre-decided alternatives (Hagerman, 1982).

Plomp-type tests are efficient due to accurate measurement of SRTs and natural sounding sentences, but have a high level of redundancy. Use of Plomp-type tests is limited in cases where frequent re-testing is required, such as research and rehabilitation applications (Dietz et al., 2014). Due to the fixed grammatical structure of sentences, a high number of unique sentences can be generated for MSTs, thereby enabling repeat testing without being vulnerable to memorisation of sentences (Boothroyd & Nitttrouer, 1988). MSTs have been

developed in a number of languages, including German (OlsA; Wagener et al., 1999a-c), Danish (DANTALE II; Wagener, Josvassen, & Ardenkjaer, 2003), Dutch (Houben, Koopman, Luts, Wagener, van Wieringen, Verschuure, & Dreschler, 2014), Finnish (Dietz et al., 2014), Spanish (Hochmuth et al., 2012), Polish (Ozimek, Warzybok, & Kutzner, 2010), and Malay (Jamaluddin, 2016).

1.6 Paediatric Speech Audiology

1.6.1 Requirements for paediatric speech perception tests.

The peripheral auditory system appears to mature early in life, in comparison to the neural processing that accompanies auditory function (Dawes & Bishop, 2008). Complex auditory processes such as auditory stream segregation, modulation detection, and recognizing degraded speech matures throughout childhood, and even into adolescence in some cases (Dawes & Bishop, 2008). The physiological immaturity of central auditory pathways, in addition to nonsensory factors such as poor attention or motivation may affect the measurement of a child's speech perception ability. Therefore, it is important to be aware of cognitive factors, working memory capacity, response task type, and whether reinforcement is used when developing a behavioural speech recognition test (Kirk et al., 1997; Kosky & Boothroyd, 2003).

Speech-audiometric tests for children should be fast and efficient, as a child's attention span can be short (Neumann et al., 2012). Material must be age-appropriate, phonemically balanced, consider the child's phonological and motoric development, and be presented with standard audiometric equipment (Mendel, 2008; Neumann et al., 2012). Potential learning effects should also be considered and test lists should be homogeneous (Neumann et al., 2012). Consideration of such factors ensures results are reflective of the

child's speech perception abilities solely and not other factors such as higher-level language abilities (Kosky & Boothroyd, 2003).

1.6.2 Existing paediatric speech perception tests.

There are a number of available speech tests, using different stimuli and providing different measures of speech perception. Existing speech tests using word stimuli include Northwestern University Children's Hearing in Pictures (NU-CHIPS) test (Elliot & Katz, 1980), the Kendall Toy Test (KTT) (Antognelli, 1989), the Early Speech Perception (ESP) Test (Moog & Geers, 1990), the Auditory Numbers Test (ANT) (Erber, 1980), Children's Realistic Inventory of Speech Perception (CRISP) and CRISP Jr. (Litovsky, 2003; Litovsky, 2005), and the Word Intelligibility by Picture Identification (WIPI) (Ross & Lerman, 1970). The NU-CHIPS and WIPI are two frequently used speech perception tests for children aged three to five years, and four to six years, respectively (Madell & Flexer, 2014). Both tests require picture-pointing responses for closed-set identification tasks, but can be performed as open-set tests (Eisenberg, Johnson, & Martinez, 2005). The NU-CHIPS presents four monosyllabic words that differ by one phoneme whereas the WIPI presents six items that are greater in similarity to each other, requiring finer auditory skills than the NU-CHIPS test (Eisenberg et al., 2005; Madell & Flexer, 2014).

Paediatric speech perception tests using sentence stimuli are also available. Common sentence-in-noise tests include the Paediatric Speech Intelligibility (PSI) Test (Jerger & Jerger, 1984), the Hearing in Noise Test for Children (HINT-C) (Nilsson, Soli, & Gelnett, 1996), and the Bamford-Kowal-Bench Speech-in-Noise Test (BKB-SIN) (Etymotic Research, 2005; Niquette et al., 2003). The BKB-SIN, a Plomp-type sentence test, was adapted from the Quick Speech in Noise Test (QuickSIN), an adaptive speech perception test for adult populations (Etymotic Research, 2001; Killion, Niquette, Gudmundsen, Revit, &

Banerjee, 2004). The BKB-SIN was developed for use with children from six years of age, and presents shorter sentences than the QuickSIN in the presence of four-talker babble. The 18 list pairs of the BKB-SIN have been equated for difficulty, and each sentence is preceded by a verbal “ready” cue (Etymotic Research, 2005). The HINT-C was adapted from the HINT, which adaptively measures speech recognition thresholds in quiet or in spectrally matched noise (Nilsson et al., 1994; Nilsson et al., 1996). This test was initially developed to assess cochlear implant candidacy of children with profound HI (Nilsson et al., 1996). HINT sentences, which are cast into 25 phonemically matched and balanced lists, were derived from BKB-SIN test material and rewritten in American English (Nilsson et al., 1994).

Matrix sentence tests (MSTs) are an alternative sentence-based measure of speech perception. Currently, only the German (Wagener, Brand, & Kollmeier, 1999b, 1999c; Wagener, Kühnel, & Kollmeier, 1999a), and Polish (Ozimek et al., 2010) MSTs have been adapted for use with paediatric populations. These are the Oldenburger Kinder-Satztest for younger children (OlKiSa; (Wagener & Kollmeier, 2005) and Polish Paediatric Matrix Sentence Test (PPMST; Ozimek et al., 2012), respectively. The OI Sa consists of five-word sentences and was developed to be a valid and reliable test assessing an adult’s speech perception ability. Younger listeners have a shorter auditory memory span, which lead to the adaption of the OI Sa to the OlKiSa, which consists of three-word pseudo-sentences, with a numeral, adjective, and object noun structure (Wagener & Kollmeier, 2005). The OlKiSa was validated by Neumann et al. (2012) as a test of speech perception in quiet for children from 4 years of age.

Stimuli of paediatric speech tests may be presented in the presence or absence of background noise, and as closed-set or open-set tests, depending on the use or non-use of pictures or words (Madell & Flexer, 2014). The appropriate protocol is decided by the child’s

auditory language age, and the ease with which the child completes a test under certain conditions (Madell & Flexer, 2014).

1.7 Paediatric speech testing in New Zealand

1.7.1 Current practice in New Zealand.

Currently, it is common practice in New Zealand (NZ) to use Consonant-Vowel-Consonant (CVC) word lists, from which the listener's correctly identified phonemes provide a measure of speech recognition (Boothroyd & Nitttrouer, 1988; Purdy, Arlington, & Johnstone, 2000). There are 10 CVC word lists, each of which consist of 10 monosyllabic, phonemically balanced words presented in quiet. Each CVC word is presented in isolation, with the carrier phrase "say" prefacing the word, after which the listener is required to repeat the presented word. Phoneme scoring is employed, and three different sentence lists presented at different intensity levels are commonly used for each ear tested. Scores are calculated as a percentage and plotted against speech stimuli presentation levels to produce a performance-intensity (PI) function. The listener's SRT can be estimated from this PI function (Boothroyd, 2008).

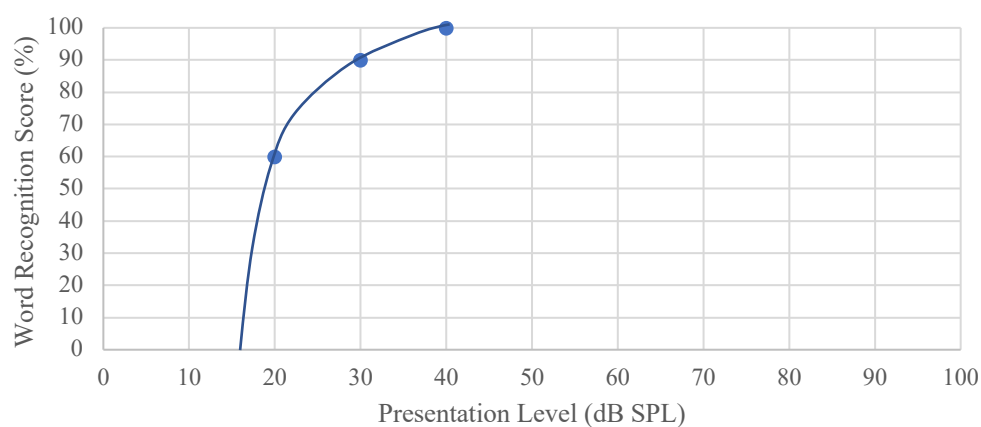


Figure 2 Example PI function.

The CVC word lists may be suitable for adolescent and older children, but some CVC words such as “tote” and “maim” may be unfamiliar to younger age groups. Additionally, the test itself may not be engaging enough for the time it would take to complete three separate word lists. The Kendall Toy Test (KTT) is an alternative speech perception test suitable for younger age groups, and it is common practice to use the KTT with paediatric populations in NZ.

1.7.2 The Kendall Toy Test.

1.7.2.1 Administration of the KTT.

The KTT is the current test of speech recognition in the paediatric audiological test battery in NZ (Ministry of Health [MOH], 2016). Test stimuli of the KTT consist of 10 monosyllabic words and five practice items, presented in quiet. Commonly, the tester covers their mouth to prevent visual cues, and asks the child to point to the item said, making the KTT a live-voice closed-set test. A sound level meter (SLM) placed next to the child indicates the sound level at which the test item is presented to the child (MOH, 2016). Familiarisation of items, and presentation of the 5 practice items at normal voice level (55 – 60 dBA) precedes the test, in which test items are presented at or below 40 dBA. Normal hearing is deemed to have been demonstrated when a child accurately discriminates 90% of items at this level (MOH, 2016).

1.7.2.2 Limitations of KTT as a speech recognition measure.

There are a number of aspects of administration of the KTT that may affect its validity as a speech perception test. The New Zealand Universal Neonatal Hearing Screening and Early Intervention Programme (UNHSEIP) diagnostic protocols specify that the SLM should be placed “with the distance between the tester and the child equal to the distance between the tester and the microphone” (MOH, 2016, p. 64). To save time, it is common for

this distance to be measured by sight only. An administration aspect such as this negatively affects inter- and intra-test reliability. In addition, there is no formal manual or NZ normative data available for the KTT. A passing level of 35 dBA was previously established with pure tone average thresholds no greater than 15 dB HL (Antognelli, 1989; MOH, 2016). Because children's hearing screening is currently conducted down to 20 dB HL in NZ, a pass level of 40 dBA is recommended for the KTT (MOH, 2016). There are a current lack of studies assessing the validity of a pass level of 40 dBA for the KTT, which calls into question its validity as a speech perception measure. The KTT also presents speech via monitored live voice. As previously mentioned, overestimation of a child's speech recognition ability has been shown with tests administered via MLV (Madell & Flexer, 2014).

Limitations of the KTT as a valid and reliable speech recognition measure suggest the need for a standardised paediatric sentence-based speech recognition test, with high reliability and validity. And although the KTT is useful for younger age groups, children within the age range that commonly attends primary school may find the test too simplistic to engage them effectively. Additionally, children within this group may not be quite old enough to be assessed using CVC word lists. Development of a more reliable and valid speech perception test, suitable for children of all ages, appears warranted.

1.8 A New Zealand Matrix Sentence Test

1.8.1 The University of Canterbury Audio-Visual Matrix Sentence Test (UCAMST).

1.8.1.1 Development of the UCAMST.

A NZ English MST, the UCAMST, was developed by O'Beirne and Trounson (2012) with the aim of adding a reliable speech-in-noise test to the adult audiological test battery. In this way, a more precise and informative measure of speech perception would be available for use within the NZ clinical context. NZ English differs from other forms of English as a

result of different formant structure and place in the vowel space (MacLagan & Hay, 2007). Because a speaker's dialect and pronunciation can negatively impact a listener's performance, the development of a MST specific to NZ English was warranted (Hochmuth et al., 2012).

The NZ English version was altered from the word matrix of the British English version to create equivalent lists without vowels that have the potential to cause confusion for NZ listeners (Hall, 2006). The UCAMST word matrix was developed by Trounson (2012) to ensure equal distribution of gender specific names across sentence lists, semantically neutral and grammatically correct sentence lists, and word categories containing a fixed number of syllables, which matched the NZ English phoneme distribution. McClelland (2015) further developed the auditory-visual mode of the UCAMST, and normalised the auditory-alone UCAMST. Equivalence of UCAMST sentence lists and conditions were then evaluated by Stone (2016), who found equivalence of sentence lists in the constant noise condition but not in the babble noise condition, and non-equivalence of open-set, closed-set, constant noise, and babble noise conditions.

1.8.1.2 Auditory-visual integration and the UCAMST.

The UCAMST uses both audio and video recordings of its stimuli. An individual's ability to recognise speech improves when they can both see and hear the talker, as opposed to hearing alone (Grant, Walden, & Seitz, 1998). The complementary nature of auditory and visual speech signals leads to a superadditive effect, whereby speech perception with auditory-visual (AV) input surpasses that predicted from the combination of speech perception in auditory-alone (AA) and visual-alone (VA) conditions (Sommers, Tye-Murray, & Spehar, 2005; Tye-Murray, Sommers, & Spehar, 2007). Exploring a listener's speech perception ability in all three listening modalities (auditory-alone, visual-alone, and auditory-

visual) allows for the provision of potentially useful diagnostic information and design of an individualised rehabilitation program that targets specific impairments (Tye-Murray et al., 2007).

Because of this, all three modalities were incorporated into the UCAMST during its development (Trounson, 2012). The modality through which the stimulus is presented can be selected to suit the objective of the assessment. Consequently, it is possible to examine an individual's ability to integrate information from any combination of the three modalities.

1.8.2 UCAMST-P: Paediatric version.

The UCAMST which utilised test stimuli consisting of five words (name, verb, number, adjective, object) was shortened to three words (number, adjective, object) to form a version of the UCAMST suitable for use with paediatric populations: the University of Canterbury Auditory-Visual Matrix Sentence Test – Paediatric Version, or the UCAMST-P (Jenkins-Foreman, 2018). The development of the UCAMST-P followed a similar methodology to the development of the OIKiSa (Neumann et al., 2012).

1.8.3 List equivalence.

1.8.3.1 UCAMST.

Sentence lists were found to be equivalent in the AV mode of presentation with regards to both SRT and slope, irrespective of response format. Sentence lists of the UCAMST were also found to be equivalent for SRT in the AA, open-set condition. However, sentence lists in the AA, open-set condition were found to differ in their slopes, and those used in the AA, closed-set condition were non-equivalent for both SRT and slope (Jenkins-Foreman, 2018), leading to the recommendation that the sentence lists be reformulated to achieve this equivalence.

1.8.3.2 UCAMST-P.

Sentence lists were found to be equivalent in the AV mode of presentation with regards to both SRT and slope, irrespective of response format. The slope of UCAMST-P intelligibility functions in the AA, closed-set condition were also found to be equivalent. Significant variation in both SRT and slope were found in the AA, open-set condition between the sentence lists used in that study; only differences in slope were found in the AA, closed-set condition. The generation of new sentence lists was therefore deemed to be required before the UCAMST-P could be used as an accurate measure of speech perception within paediatric populations, with sentence lists that are equivalent with respect to SRT and slope in all conditions.

1.8.4 SRT tracking procedure.

1.8.4.1 UCAMST.

The UCAMST uses an adaptive tracking procedure in which slope and SRT are simultaneously estimated. Two points on the psychometric function, typically the 20% and 80% correct points, are adaptively tracked (Jenkins-Foreman, 2018). A psychometric function can be extrapolated from the 20% and 80% correct points, and from this the SRT and slope can be measured. As a result, the UCAMST provides a highly reliable and efficient measure, circumventing floor and ceiling effects.

1.8.4.2 UCAMST-P.

As the UCAMST-P will be used with paediatric populations, the time taken to measure a child's SRT was an important consideration in the design of this test. To minimise the amount of time taken to accurately measure SRT, only one point on the psychometric function is adaptively tracked, the 50% correct point. In the UCAMST-P, the slope of

psychometric functions cannot be measured, as a psychometric function cannot be extrapolated solely from the 50% correct point.

1.9 Current study

1.9.1 Rationale for current project.

1.9.1.1 Normative data.

Performance on auditory listening tasks has been demonstrated to improve as children mature and develop (Wilson, Farmer, Gandhi, Shelburne, & Weaver, 2010). The developmental trajectory of children necessitates the establishment of age-related norms for behavioural speech intelligibility tasks (Holder, Sheffield, & Gifford, 2016; Ng et al., 2011; Wilson et al., 2010). Currently, the clinical use of the UCAMST-P is hampered by the lack of a normative data set. To allow for confident interpretation of UCAMST-P test scores, this study aimed to gather normative data from children aged 6 to 12 years with normal hearing.

Past studies that aimed to collect normative data for speech-in-noise tests were reviewed to determine the number of participants required and age brackets for analysis for this study. When gathering normative values for the BKB-SIN, scores fell into three groups, each statistically significant from the other two (Ng et al., 2011). The three groups were 5-6 years, 7-10 years, and 11-14 years (Ng et al., 2011). In another study, participants were separated into four age groups: 5-6 years, 7-8 years, 9-10 years, and 11-12 years, when gathering normative data in the sound field for the BKB-SIN (Holder et al., 2016). Neumann et al. (2012) grouped participants according to their age in years and did not group ages together. Such studies demonstrate the variability with which participants are grouped for analysis in studies gathering normative data. Greater variability in scores have been observed for younger children compared to older children, due to a greater variability in development in younger age groups (Holder et al., 2016; Ng et al., 2011; Wilson et al., 2010).

1.9.1.2 List equivalence.

With the UCAMST-P, greater variability in speech intelligibility functions of sentence lists was present in the AA, open-set condition (Jenkins-Foreman, 2018). Greater variability indicates non-equivalent difficulty of sentence lists and inconsistency of estimating a listener's SRT between sentence lists in the AA, open-set condition (Jenkins-Foreman, 2018). In order for the UCAMST-P to be a valid test, new sentence lists needed to be generated that were equivalent with respect to estimation of a listener's SRT (Jenkins-Foreman, 2018).

1.9.2 Aims.

The present study aimed to (1) generate new sentence lists of the UCAMST-P for use with paediatric populations, (2) assess the equivalence of the newly generated sentence lists, and (3) establish normative data for children with normal hearing aged 6 to 12 years for the UCAMST-P. Extra information was to be gathered about each participant on factors such as gender, household income, ethnicity, developmental factors, and academic achievement; with analysis of the data collected indicating if any association was present between performance on a speech test and these factors.

1.9.3 Research questions.

The current research project endeavoured to answer the following three research questions:

- 1) Will UCAMST-P performance improve as a function of increasing age for a paediatric population of six to twelve-year olds?
- 2) Are the test lists equivalent with regards to speech recognition thresholds?

- 3) Is there an association between performance on the UCAMST-P and factors such as ear tested, gender, household income, ethnicity, developmental factors, and academic achievement?

1.9.4 Hypotheses.

The ensuing hypotheses are proposed for the three research questions:

- 1) It is hypothesised that a significant negative relationship is present between age and speech reception threshold, i.e. scores will improve with age.
- 2) It is hypothesised that there will be no significant differences between the UCAMST-P sentence lists with regards to speech reception threshold.
- 3) It is hypothesised that there will be no significant differences between performance on the UCAMST-P and factors such as ear tested, gender, household income, ethnicity, developmental factors, and academic achievement.

2 Methods

2.1 Overview

As discussed in the previous chapter, this study was conducted to collect normative data for the UCAMST-P for six to 12-year-olds, and generate and assess equivalence of new sentence lists. This study was run in conjunction with another Master of Audiology study (Yau, in progress), which aimed to collect normative data for the University of Canterbury Adaptive Speech Test – Filtered Words (UCAST-FW) for the same age groups.

Ethical approval was gained on 18 July 2018 from the University of Canterbury Educational Research Human Ethics Committee prior to commencement of the research (see Appendix A.1 for a copy of the letter of approval). An amendment was approved on 25 September 2018 (see Appendix A.2) to add a third recruitment pathway. The procedures employed in the current research project were run in accordance with that stipulated in the approved ethics application and amendment.

2.2 Participants

2.2.1 Recruitment.

Participants were recruited from local primary schools and the “Learning to Talk” study database housed in the New Zealand Institute of Language Brain and Behaviour (NZILBB) at the University of Canterbury. It was decided after testing had started to add a third recruitment pathway, as there was a lack of 12-year old participants. Participants were recruited from the “Dorayme Music Tuition Studio Ltd” music school in Christchurch.

Participants were grouped according to age; six groups were formed from the six different ages included in this study. A G*Power 2 power analysis, using an effect size of 0.6, indicated 11 participants per age group were required to afford sufficient statistical power. As

the goal was to collect normative values, it was decided that testing as many participants as possible would be of most benefit to the study.

An email invitation was circulated to parents/guardians via teachers during recruitment from primary schools and the music school, or, when recruiting from the “Learning to Talk” study database, directly via the manager of that database at the NZILBB. An information sheet outlining the inclusion criteria of participants, and the extent to which children and parents/guardians would be involved in the study, was included in the invitation (see Appendices B.1 and B.2). Teachers involved in identifying participants and/or completing a questionnaire for participants were given a separate information sheet (see Appendices B.5 and B.6) and required to fill out a separate consent form (see Appendix C.2).

Parents/guardians of children recruited from schools returned consent forms to teachers, which were passed on to the researchers; parents of children in the “Learning to Talk” database returned consent forms to the researcher directly (see Appendix C.1 for the parent/guardian consent form). Children who participated also read and signed the information sheet and assent forms (see Appendices B.3 and B.4 for information sheets, and Appendixes D.1 and D.2 for assent forms). As a token of appreciation, a \$10 Motor Trade Association voucher was given to the parent or guardian of each participant. A free full diagnostic hearing assessment at the University of Canterbury Speech and Hearing clinic was offered to children who did not pass the hearing screen.

2.2.2 Inclusion criteria.

To meet the inclusion criteria, participants were required to be six to 12 years of age, speakers of NZ English, and have normal hearing. The inclusion criteria also required participants to have no history of hearing issues, neurological impairment, middle ear

infections or surgeries. Participants identified in any of these categories still completed the full assessment, to provide data that may be of use in future studies. The data collected from participants not meeting the inclusion criteria was excluded from the current study's data analysis.

2.3 Equipment

2.3.1 Overview.

Equipment used to screen the hearing of participants assessed at school differed from that used to screen participants at the University of Canterbury. Equipment for audiology assessment was readily available in the audiology clinics at the university, whereas portable equipment was required for assessment at schools. The technology with which the UCAMST-P and UCAST-FW tests were run also differed slightly between testing locations.

The UCAMST-P was developed by Professor Greg O'Beirne with LabVIEW. The resultant data was investigated in Microsoft Excel version 16.18, and all statistical analyses were run with version 25.0.0.0 of the IBM Statistical Package for the Social Sciences (SPSS).

2.3.2 Equipment used with participants from the “Learning to Talk” Database.

The initial hearing screen was carried out using a calibrated Grason-Stadler GSI 61 clinical audiometer and Telephonics TDH-50P supra-aural headphones. Participants pressed a response button connected to the GSI 61 audiometer in response to octave pure-tones presented at 0.5, 1, 2, and 4 kHz. Tympanometry was carried out with a calibrated Inventis Clarinet tympanometer with a probe tone of 226 Hz and sweep rate of 200 daPa/s, as is standard in New Zealand (New Zealand Audiological Society, 2015).

The UCAMST-P and UCAST-FW tests were run on an HP EliteDesk 800 G1, and displayed on an Elo touch-sensitive monitor. Auditory stimuli was presented with Senheiser HD 280 Pro circumaural headphones (64 Ω impedance) via a THX Sound Blaster sound card connected to the HP EliteDesk 800 G1. Participants responded in the UCAST-FW test by selecting one of four pictures presented on the touch-screen monitor, and verbally in the UCAMST-P, to which the tester selected correctly identified items.

2.3.3 Equipment used for testing participants from primary schools and the music school.

Pure-tone audiometry testing was administered using calibrated portable Interacoustics AS208 screening audiometers and Peltor circum-aural headphones. Participants pressed a response button connected to the AS208 screening audiometer in response to octave pure-tones presented at 0.5, 1, 2, and 4 kHz. An Interacoustics MT10 portable tympanometer was used to obtain tympanograms.

Both the UCAMST-P and UCAST-FW tests were run using an HP EliteBook Revolve 810 Notebook. Auditory stimuli was presented with Sennheiser HD 280 Pro (64 Ω impedance) circumaural headphones, via a THX Sound Blaster sound card connected to the HP EliteBook Revolve 810 Notebook. Participants responded in the UCAST-FW test by selecting one of four pictures presented on the HP Notebook touchscreen, and verbally in the UCAMST-P, to which the tester selected items correctly identified.

2.4 Stimuli

2.4.1 Generation of new sentence lists.

New sentence lists were constructed using data previously generated both with and without practice, in the auditory-alone, open-set condition (Jenkins-Foreman, 2018). From

the existing 16 sub-lists, sentences that produced SRT outliers or poor SRT measures were removed from the stimuli set, and sentences were rearranged between the sentence lists with the aim of reducing the standard deviation of the SRTs. As a result, 12 new lists of 10 sentences were generated, improving the mean SRT from -5.51 ± 4.34 dB SNR to -6.30 ± 0.66 dB SNR. The new lists also met the original constraints of (1) no replicate two-word pairs within a single list (for example, no repeats of “eight new” or “old spoons”), and (2) no identifiable visual patterns in response positions in the matrix. These revised lists are presented in Appendix F.1.

2.4.2 Stimuli number.

Compared to the current study, a greater number of sentences were delivered in each test in the study by Jenkins-Foreman (2018), in which the UCAMST-P was formed and equivalence of UCAMST-P sentence lists were investigated with adult populations. In that study, 40 sentences were delivered in each test condition, as reliable SRT levels were attained when a minimum of 30 sentences were employed (Brand & Kollmeier, 2002). Because it is likely a child’s ability to pay constant attention to a task is less advanced than an adult’s, fewer sentences per test were used in this study, resulting in a shorter test (Betts, McKay, Maruff, & Anderson, 2006). Twenty sentences, formed by combining two of twelve available ten-sentence lists, were presented to each participant. The two sentence lists used were randomly chosen via the software.

2.5 Experimental Procedures

A questionnaire focused on the child’s general health, ear health history, and family context was filled out by a parent/guardian of each child (see Appendix E.1). A separate questionnaire focused on the language, behaviour, reading and writing development of the child, and their listening behaviour at school, was filled out by the participant’s school

teacher (see Appendix E.2). Each participant read the information sheet through with the researcher and signed an assent form, prior to participating in the study. Only participants who had signed the assent form and had their parent/guardian give consent, either verbally or written, participated in the study.

All testing was carried out in an audiology clinic room at the Department of Communication Disorders, University of Canterbury, or a classroom set aside for testing at the school the participant attended. For participants recruited directly from local schools, testing was able to be carried out in a quiet, though not sound-treated room with portable equipment and Peltor circum-aural headphones.

Each child completed an initial hearing screen, in addition to the UCAST-FW and UCAMST-P tests in one assessment session, taking breaks when needed. The duration of a full assessment session was approximately 45 minutes. Otoscopy was performed to ascertain no debris or wax was present in the ear canals that may affect accuracy of the hearing screen. Tympanometry assessed the presence of a middle ear abnormality such as an ear infection or eardrum perforation, or the status of a ventilation tube. The preliminary hearing screen was conducted down to 20 dB HL at 0.5, 1, 2, and 4 kHz bilaterally. Normal hearing was ascertained when hearing thresholds did not exceed 20 dB HL in any of the frequencies assessed. Participants were given a copy of their hearing screen to give to their parent or guardian; those who did not pass the screen received a sheet that recommended a full audiological assessment (see Appendices G.1 and G.2 for hearing screen result sheets indicating a passed hearing screen or one requiring further audiological assessment, respectively).

2.5.1 Conditions in which the UCAMST-P was administered.

Greater variability in development is present in younger age groups, therefore, a wider range of reading abilities may be present within the younger age brackets (Holder et al., 2016). To avoid a reading artefact, we decided to gather normative data in the AA, open-set condition. The UCAMST-P was performed with stimuli presented monaurally to the left and right ear, separately. Each participant completed the UCAST-FW with stimuli presented monaurally to the left ear and right ear, and binaurally, in separate runs. The order with which stimuli was presented to the left ear, right ear, and binaurally, and the order with which the UCAST-FW and UCAMST-P tests were administered, was counterbalanced between participants. The hearing screen was administered prior to either the UCAST-FW or UCAMST-P tests (whichever was administered first) for all participants.

2.5.2 Operation of the UCAMST-P.

Prior to starting the UCAMST-P, the tester explained to the participant that they would hear sentences in the presence of noise of varying intensity. Participants were instructed to verbally respond with what they heard and encouraged to guess when uncertain. To familiarise the participants, a list of the 18 words used in the matrix of the UCAMST-P were read aloud by the participant from a sheet of paper, or were modelled by the tester when the participant was unable to correctly read a word. The matrix of words can be seen in Figure 1.

2	big	bikes
3	small	books
8	new	hats
9	old	shoes
10	green	spoons
12	red	toys

Figure 3: Matrix of words used in the UCAMST-P.

When the participant verbally responded, the tester scored the words that were correctly identified using a separate interface. Another sentence was then presented to the participant, until all 20 list sentences were completed in one condition.

2.6 Measures

2.6.1 Scoring procedures.

Word-based scoring procedures were used in the current study as steeper slope scores were obtained for the UCAMST with this method in a previous study (McClelland, 2015). As discussed earlier, steeper slopes indicate a less variable and more accurate SRT measure. The number of words correctly identified for an individual sentence is recorded, giving a score out of three for each sentence, which is converted to a percentage score that is either 0%, 33.3%, 66.7%, or 100%.

2.6.2 SRT measurement.

There are two adaptive modes the UCAMST is programmed to use, both of which are described in Brand & Kollmeier (2002): The A1 procedure, which takes 20 trials to find the 50% SRT (but doesn't always give a reliable estimate of slope); and A2, which takes 30 trials to reliably find both the SRT and the slope of the psychometric function (by simultaneously tracking the 20% and 80% correct points on the function). The procedure used in the previous

study by Jenkins-Foreman (2018) was the A2 procedure, whereas the SNR tracking procedure used in this study was the A1 procedure. This procedure was chosen to avoid a child's reduction in attention and motivation that may occur as a result of increased difficulty of the task on those trials when the SNR is converging on the 20% correct point of the psychometric function (Betts et al., 2006). As a result, the slopes of the psychometric functions were not measured or analysed in this study. Mean SRT values of each age group were to be evaluated in this study to calculate the performance of each age group.

2.7 Planned statistical analyses

A correlational analysis will be used to test the hypothesis for research question one: *Will UCAMST-P performance improve as a function of increasing age for a paediatric population of six to twelve-year olds?* Multivariate ANOVA analyses will be used to test the hypotheses for research questions two and three: *Are the test lists equivalent with regards to speech recognition thresholds?* and, *Is there an association between performance on the UCAMST-P and factors such as ear tested, gender, household income, ethnicity, developmental factors, and academic achievement?*

3 Results

3.1 Participants

The UCAMST-P was administered to 144 normal-hearing participants aged five to 13 years old (86 male, 58 female, 0 gender diverse). Twenty-seven of these children did not pass the hearing screen: eleven did not pass with the right ear only; eight did not pass with the left ear only; and eight did not pass the hearing screen with either ear. The data of participants who did not pass the hearing screen with one ear but passed with the other were included in the final analysis to contribute to separate ear information. Two five-year olds and two 13-year olds participated in this study because they were recruited by teachers; this data was not used in the final analysis but may be analysed in future studies. Inspection of the data revealed five participants with outlying SRT results either for the left or right ear, or outlying mean combined SRTs of the two ears. These scores were also removed from the final data analysis. Normality of data was assumed due to the large sample size.

3.2 Separate Ear Results

Table 1: Age-specific mean SRT with standard deviation (SD), upper and lower bounds of 95% confidence interval, and median SRT with 90th and 10th percentiles. N_{total} = total number of participants, N_{valid} = number of participants who passed the hearing screen in the respective ear, RE = right ear, LE = left ear.

Age (years)	N _{total}	N _{valid}	Right Ear			Median SRT with 90th (P90) and 10th (P10) percentiles (dB SNR)	N _{valid}	Left Ear			Median SRT with 90th (P90) and 10th (P10) percentiles (dB SNR)
			Mean RE SRT ± 1SD (dB SNR)	95% Confidence Interval (dB SNR)				Mean LE SRT ± 1SD (dB SNR)	95% Confidence Interval (dB SNR)		
				Lower Bound	Upper Bound				Lower Bound	Upper Bound	
6	16	12	-4.233 ± 1.573	-5.056	-3.411	Median: -4.600 P90: -1.290 P10: -6.190	12	-4.758 ± 2.047	-5.608	-3.909	Median: -4.800 P90: -2.020 P10: -8.220
7	16	15	-5.400 ± 1.085	-6.135	-4.665	Median: -5.500 P90: -3.880 P10: -6.860	13	-4.931 ± 1.433	-5.747	-4.115	Median: -4.800 P90: -3.040 P10: -7.100
8	21	20	-5.575 ± 1.526	-6.212	-4.938	Median: -5.800 P90: -3.300 P10: -7.380	19	-5.184 ± .913	-5.859	-4.509	Median: -5.200 P90: -3.700 P10: -6.800
9	19	14	-6.014 ± 1.379	-6.776	-5.253	Median: -6.050 P90: -4.300 P10: -8.050	16	-5.575 ± 1.534	-6.311	-4.839	Median: -5.800 P90: -3.190 P10: -7.320
10	24	23	-6.248 ± 1.520	-6.842	-5.654	Median: -6.400 P90: -4.200 P10: -8.160	23	-6.204 ± 1.563	-6.818	-5.591	Median: -5.900 P90: -4.580 P10: -8.480
11	13	12	-5.992 ± 1.003	-6.814	-5.169	Median: -5.950 P90: -4.730 P10: -7.940	13	-6.100 ± 1.565	-6.916	-5.284	Median: -5.900 P90: -4.040 P10: -8.740
12	16	13	-6.646 ± 1.727	-7.436	-5.856	Median: -6.500 P90: -3.900 P10: -8.940	15	-6.667 ± 1.334	-7.427	-5.907	Median: -6.900 P90: -4.480 P10: -8.620

3.2.1 Right ear.

The SRTs for the right ear are shown for the different age groups in Figure 2 below.

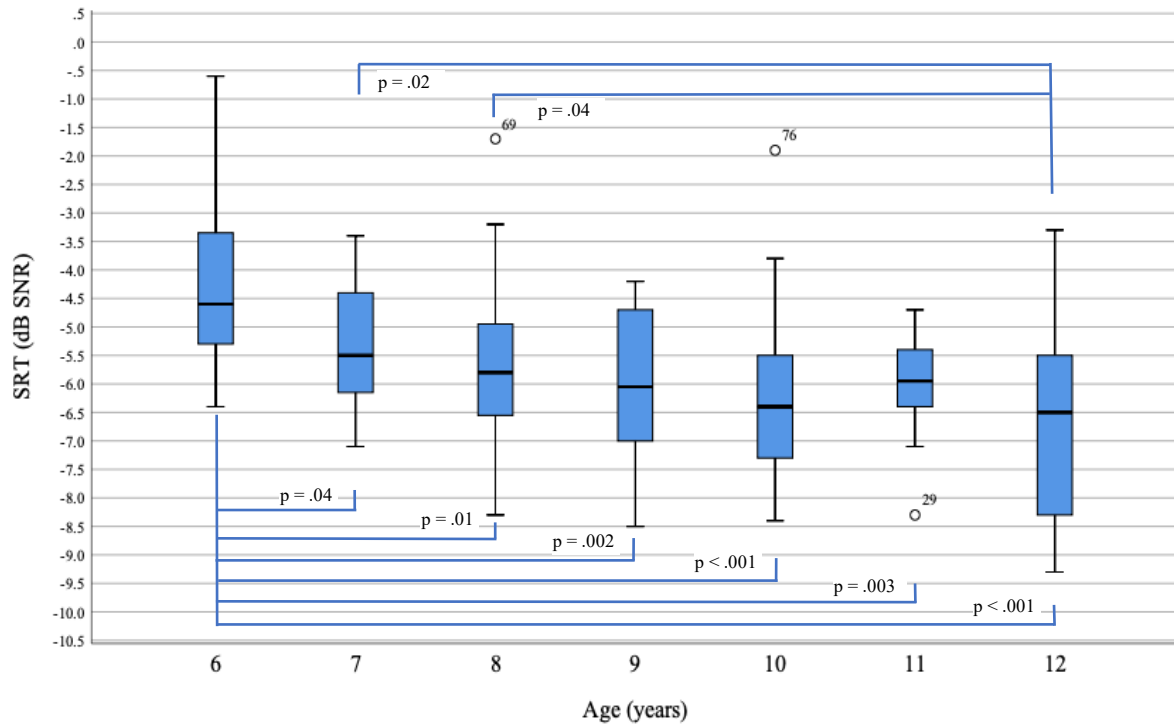


Figure 4: Boxplots of SRT measures for the right ear only, across the six age groups. Only the SRT measures of participants who passed the hearing screen with the right ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparison using least significant differences [LSD] correction).

Levene's test was not significant, indicating equality of variances of SRT across the seven age groups. A univariate analysis of variance (ANOVA) indicated a significant main effect of age on SRT, $F(6, 102) = 3.86$, $p = .002$, $\eta^2 = .19$.

Post-hoc pairwise comparisons using the LSD correction revealed the following significant differences, shown in Table 2:

Table 2: Post-hoc pairwise comparisons in right ear SRT using the LSD correction.

		Age (years)					
		7	8	9	10	11	12
Age (years)	6	.04	.01	.002	< .001	.003	< .001
	7						.02
	8						.04

There were no other significant differences.

3.2.2 Left ear.

The SRTs for the left ear are shown for the different age groups in Figure 3 below.

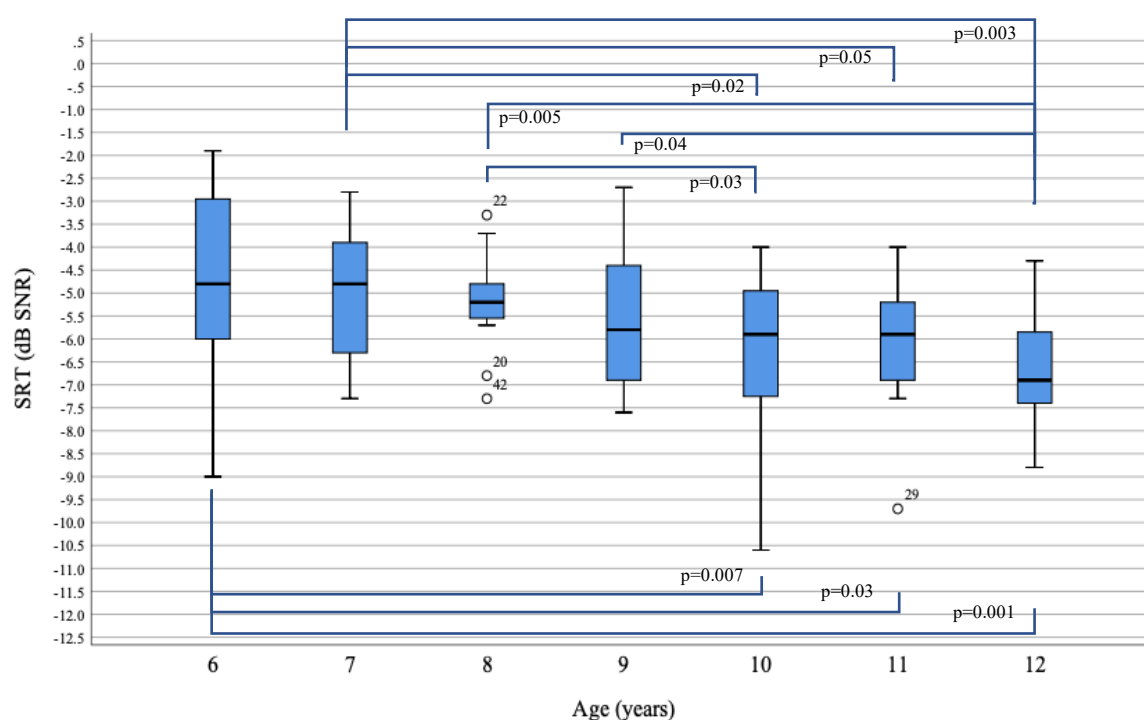


Figure 5: Boxplots of SRT measures for the left ear only, across the six age groups. Only the SRT measures of participants who passed the hearing screen with the left ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparison using LSD correction).

Levene's test was not significant, indicating equality of variances of SRT across the seven age groups. A univariate ANOVA indicated a significant main effect of age on SRT, $F(6, 104) = 3.45$, $p = .004$, $\eta^2 = .17$.

Post-hoc pairwise comparisons using the LSD correction revealed the following significant differences, shown in Table 3:

Table 3: Post-hoc pairwise comparisons in left ear SRT using the LSD correction.

		Age (years)		
		10	11	12
Age (years)	6	.007	.03	.001
	7	.02	.05	.003
	8	.03		.005
	9			.04

There were no other significant differences.

3.3 Combined Ear Results

Combined SRT measures were calculated for each participant, equivalent to the average of the separate SRTs of the left and right ears. The combined SRTs for each age group are shown in Figure 4 below.

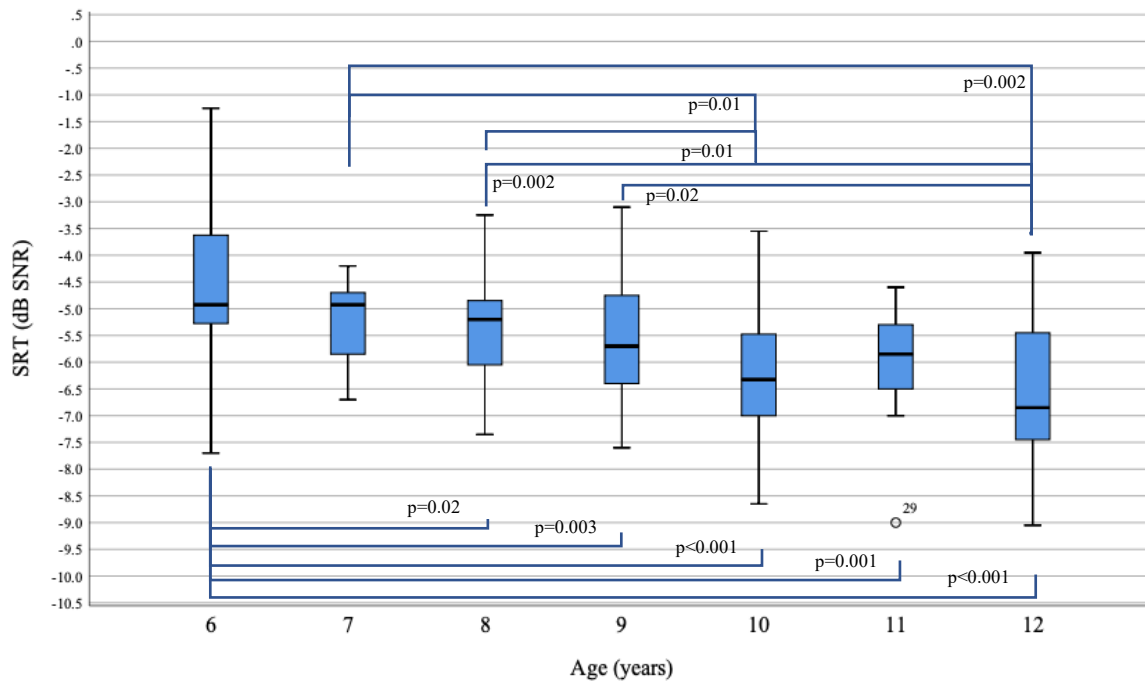


Figure 6: Boxplots of combined SRTs, calculated from the average of the left and right ear SRTs, across the six age groups. Only the SRT measures of participants who passed the hearing screen with at least one ear were included in this graph. Non-significant outliers are indicated by circles. SRTs that are significantly different from each other are indicated (post-hoc pairwise comparisons using the LSD correction).

Levene's test was not significant for the combined SRT measures, indicating equality of variances of SRT across the seven age groups. A univariate ANOVA indicated a significant main effect of age on SRT, $F(6, 118) = 6.22$, $p < .001$, $\eta^2 = .24$.

Post-hoc pairwise comparisons using the LSD correction revealed the following significant differences, shown in Table 4:

Table 4: Post-hoc pairwise comparisons in combined SRT using the LSD correction.

		Age (years)				
		8	9	10	11	12
Age (years)	6	.02	.003	< .001	.001	< .001
	7			.01		.002
	8			.01		.002
	9					.02

There were no other significant differences.

3.3.1 Co-variates.

Co-variates explored in this study included the participant's current and past achievement or non-achievement of curriculum standards, presence of typical or non-typical development, household income, and ethnicity. Non-typical development was a broad term used in this study and was defined as presence or history of any of the following: attention deficit hyperactivity disorder (ADHD), autism spectrum disorder (ASD), Asperger syndrome, developmental delay, history of speech-language therapy or speech and language delay, auditory processing disorder (APD), chronic middle ear infections and/or middle ear surgery, learning disability, and dyslexia. Age-specific SRTs for each co-variate are shown in Figures 5 to 9 below, with the exceptions of ethnicity and household income. These two variables were not presented in boxplot form, due to the minimal number of participants in certain ethnicity groups and income brackets.

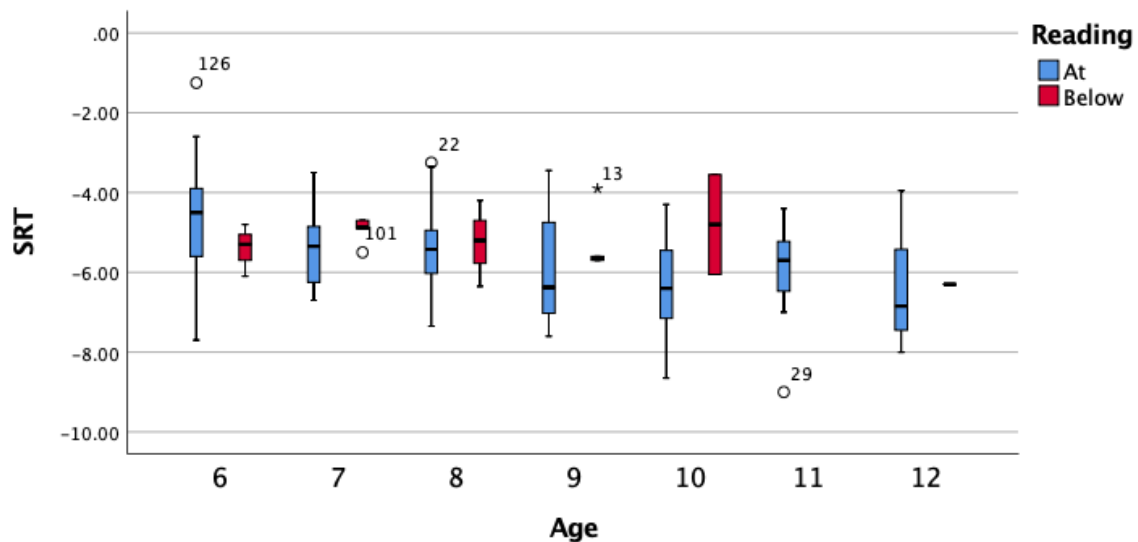


Figure 7: Boxplots of age-specific combined SRTs of participants who currently and have always met the reading curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the reading curriculum standard (“Below”). Significant outliers indicated by asterisks, non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.

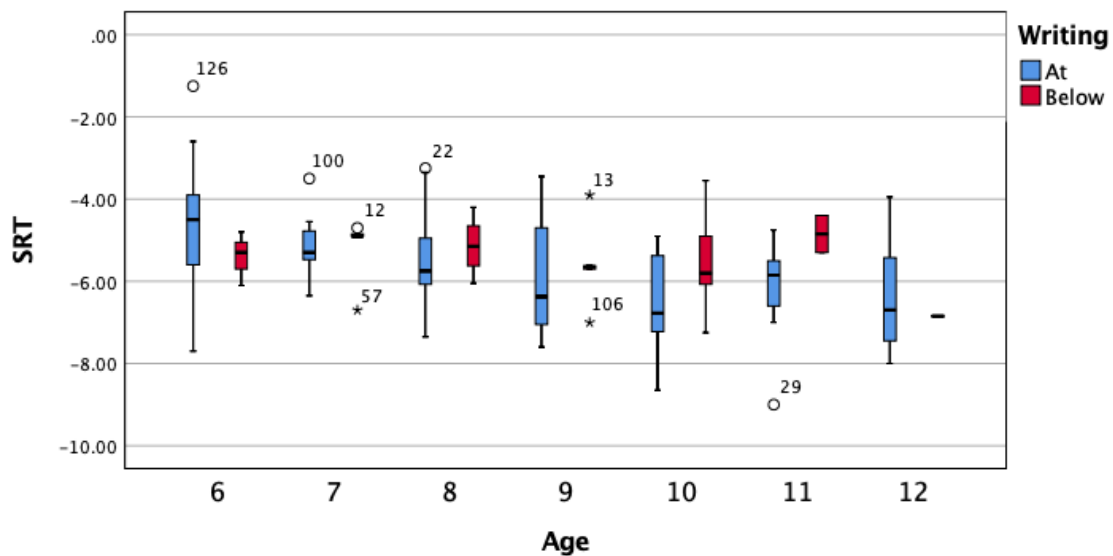


Figure 8: Boxplots of age-specific combined SRTs of participants who currently and have always met the writing curriculum standard (“At”), and participants who are not currently meeting and/or in the past not met the writing curriculum standard (“Below”). Significant outliers indicated by asterisks, non-significant outliers indicated by circles.

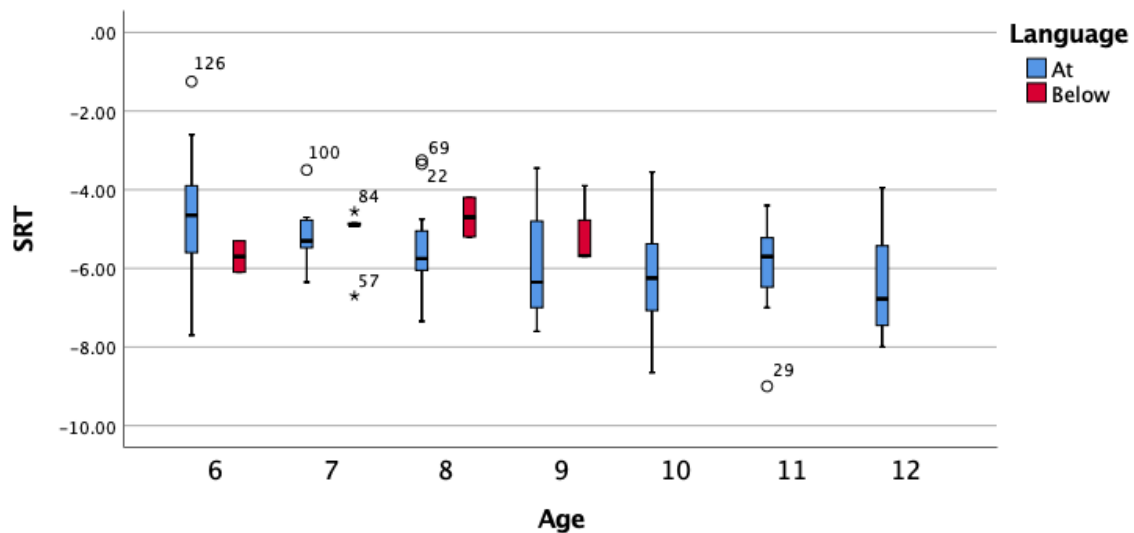


Figure 9: Boxplots of age-specific combined SRTs of participants who currently and have always met the language curriculum standard ("At"), and participants who are not currently meeting and/or in the past not met the language curriculum standard ("Below"). Significant outliers indicated by asterisks, non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.

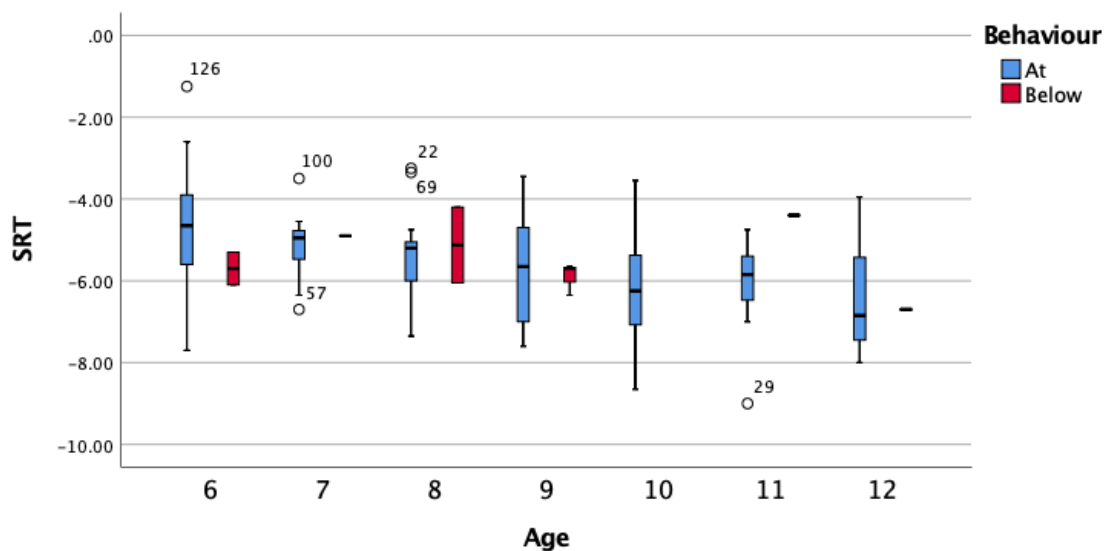


Figure 10: Boxplots of age-specific combined SRTs of participants who currently and have always met the behaviour curriculum standard ("At"), and participants who are not currently meeting and/or in the past not met the behaviour curriculum standard ("Below"). Non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.

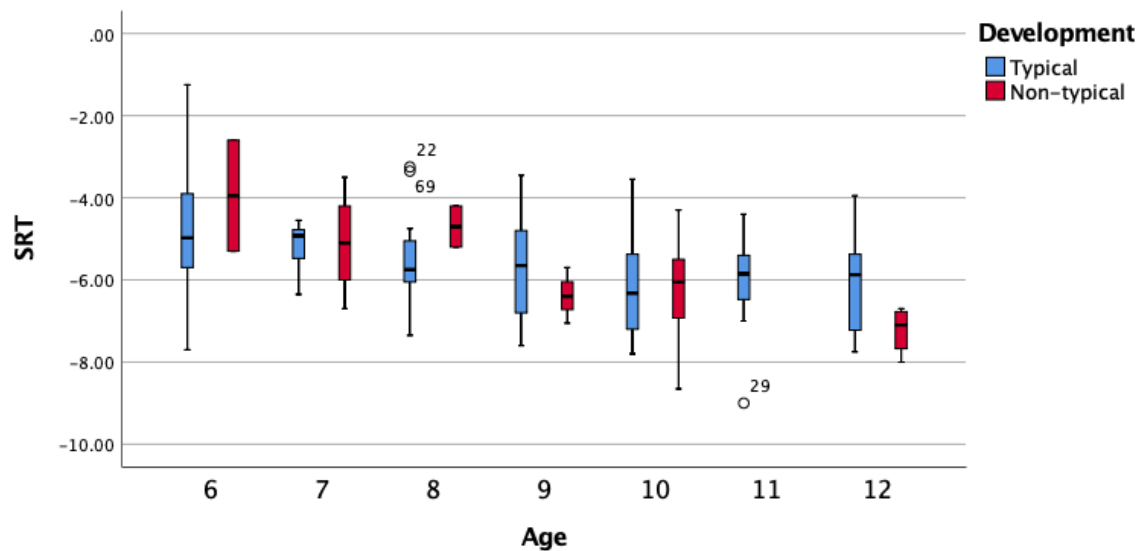


Figure 11: Boxplots of age-specific combined SRTs of participants with reported typical and non-typical developmental history. Non-significant outliers indicated by circles. Lack of a boxplot indicates no participants within that category.

A regression analysis was run to determine the possible influence of these nuisance variables on combined SRT measures. None of the nuisance variables were significant.

3.4 Gender Effect

SRTs for the right ear and left ear (Figures 10 and 11, respectively), and combined SRTs (Figure 12) of male and female participants across all six age groups are shown below.

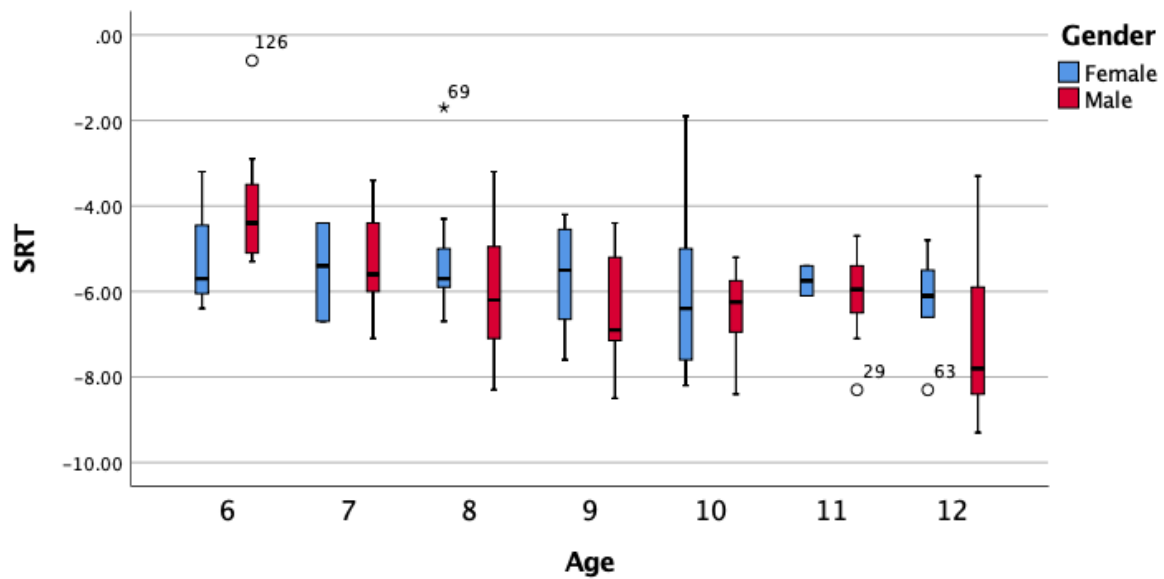


Figure 12: Boxplots of right ear SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with the right ear were included in this graph. Significant outliers indicated by asterisks, non-significant outliers indicated by circles.

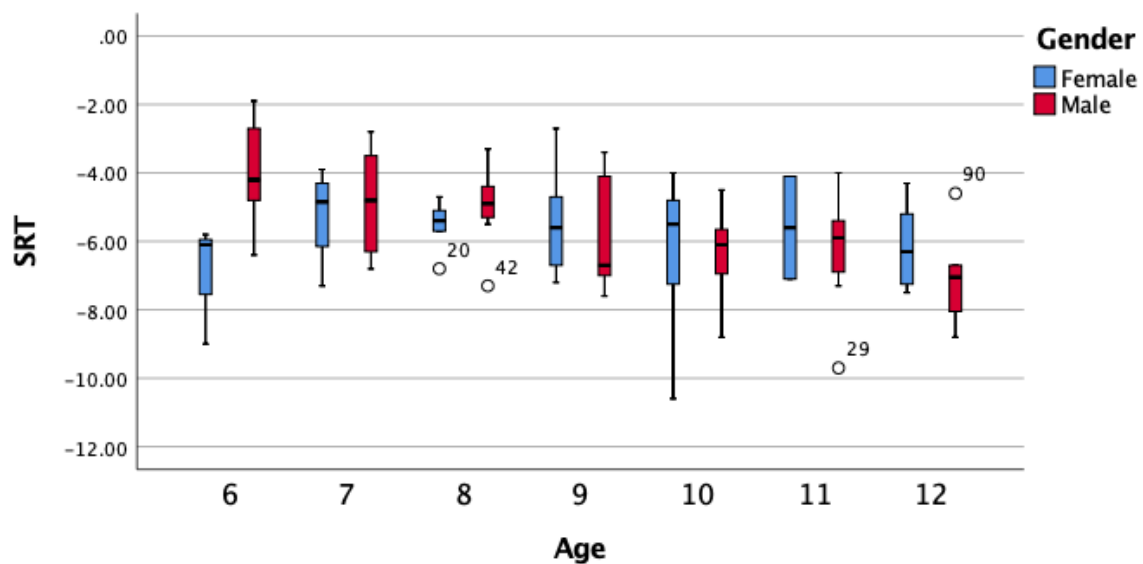


Figure 13: Boxplots of left ear SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with the left ear were included in this graph. Non-significant outliers indicated by circles.

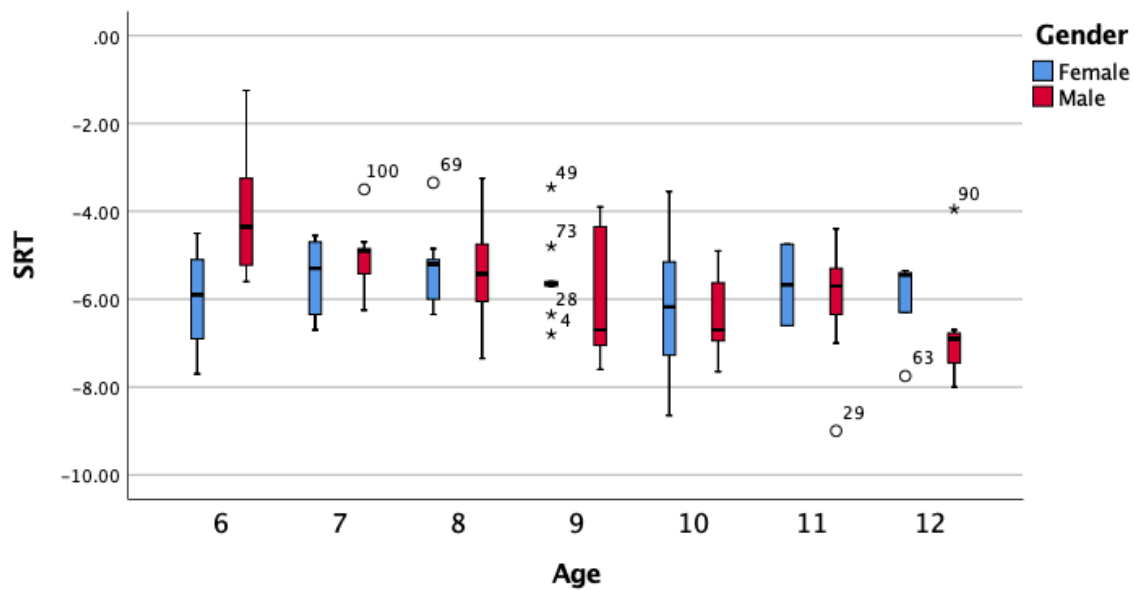


Figure 14: Boxplots of combined SRTs of male and female participants for each age group. Only SRT measures of participants who passed the hearing screen with at least one ear were included in this graph. Significant outliers indicated by asterisks, non-significant outliers indicated by circles.

A univariate ANOVA indicated no significant main effect of gender for both the right ear, $F(1, 109) = .04$, $p = .84$, $\eta^2 < .001$, and the left ear, $F(1, 111) = .73$, $p = .40$, $\eta^2 = .006$. No significant main effect of gender was also demonstrated with a univariate ANOVA on combined SRT measures, $F(1, 125) = .82$, $p = .37$, $\eta^2 = .006$. Levene's test was not significant for all three SRT measures, indicating equality of variances of right ear SRT, left ear SRT, and combined SRTs, for both female and male groups.

3.5 Ear Effect

The SRTs of the right and left ears for all age groups are shown in Figure 17 below.

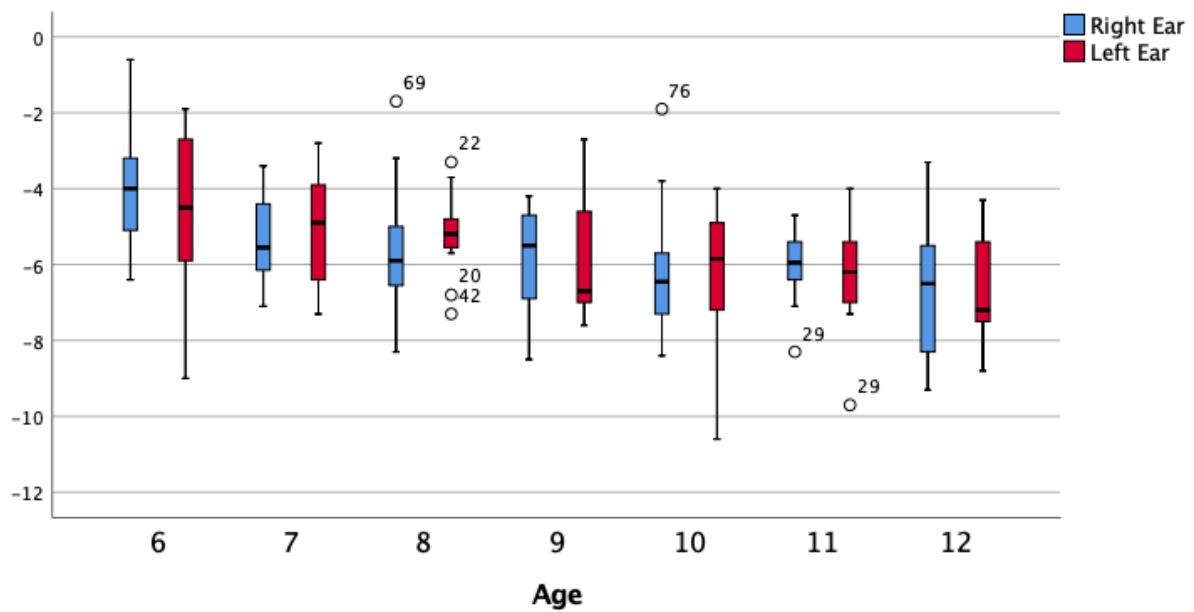


Figure 15: Boxplots of right and left ear SRTs for each age group. Non-significant outliers indicated by circles.

A repeated measures ANOVA indicated no significant main effect of ear, $F(1, 102) = .28$, $p = .60$, $\eta^2 = .003$. Mauchly's test was not significant, therefore sphericity was assumed in the analysis.

3.6 Sentence List Equivalence

The mean SRT of each sentence stimuli, and therefore each sentence list, was unable to be assessed due to time constraints of the current study. Due to this, no statistical analyses of sentence list equivalence could be run. As the slopes of psychometric functions could not be measured, it was not possible to determine the presence of significant differences between the newly generated sentence lists with regards to slope. However, the SD of SRTs measured with adult participants in a previous study (Jenkins-Foreman, 2018), was greatly reduced with the new sentence lists (from -5.51 ± 4.34 dB SNR to -6.30 ± 0.66 dB SNR), indicating an improved equivalence of these sentence lists.

4 Discussion

4.1 Introduction

The primary aim of this study was to produce normative data for the UCAMST-P for six to 12-year olds. New sentence lists were generated for the UCAMST-P, with the aim of increasing the equivalence of sentence list stimuli. Secondary to this, the association between UCAMST-P performance and the following factors was investigated: ear tested, gender, household income, ethnicity, developmental history, and academic achievement.

A positive developmental trajectory in SRT scores was found from six to 10 years of age. SRT scores then appeared to plateau for the 11 and 12-year-old age groups. It is interesting to note that although no ear effect was found, the specific age groups between which significant differences in SRT scores were found, were different between the left and right ears. The small number of participants per age group may contribute towards these contrasting findings.

No significant effect of gender, household income, ethnicity, developmental history, or academic achievement on UCAMST-P performance was found. It would be advisable to repeat the investigation with a greater number of participants as the small sample size may have negatively impacted the accuracy of this finding.

4.2 Main Effects of Age, Ear, and Gender

4.2.1 Age Effect.

It was hypothesised that a significant negative relationship would be present between mean SRT and age, i.e. that SRT scores would improve with age. Mean SRT scores of the left and right ears appeared to improve with age across the six, seven, eight, nine, and 10-year-old age groups. A plateau in mean SRTs across the 10 to 12-year-old age groups was

demonstrated by a lower mean SRT for the 11-year-old group compared to the 10 and 12-year-old groups.

Anatomical studies have shown the development of the human auditory cortex up until adolescence. Growth of intrahemispheric and interhemispheric axons within the brain occurs from five to 12 years of age, allowing greater complexity in cortical processing of auditory stimuli (Moore, 2002). As a result, increased complexity of cortical processing, demonstrated by improved perception of speech in noise, has been shown to improve steadily across late childhood and early adolescence (Moore, 2002). Growth in this way constitutes the final stage of maturation of the human auditory cortex, and may explain the improvement and subsequent plateau in SRT scores seen across the age groups in this study.

Increased speech recognition ability as a child matures may also be attributed to increased phonological awareness or vocabulary growth, linguistic ability, cognitive development, and utilisation of sensory information (Eisenberg et al., 2000; Hnath-Chisolm, Laipply, & Boothroyd, 1998; Ross et al., 2011). It follows that speech perception tests should be developed that produce results maximally dependent on sensory capacity as opposed to other language, cognitive, and maturational factors (Hnath-Chisolm et al., 1998).

Administration of the UCAMST-P involved familiarising the child with the 18 words that may be used, with the aim of minimising influence of vocabulary knowledge and linguistic ability on SRT estimation. Different to the UCAMST which was used with adults, three-word sentences were used instead of five-word sentences, which minimised the influence of other factors. Cognitive, maturational and language factors may still have contributed somewhat to the modest improvement in SRT scores up to the age of 10. For example, an age-related increase in attention may have contributed towards the modest increase in SRT with age in this study (Neumann et al., 2012).

Elliott et al. (1979) suggests that frequency of word usage increases inherently with chronological age, and a “cumulative” frequency of word usage may account for improved speech recognition with older age groups, independent of vocabulary knowledge. Thus, it is expected that older age groups would produce greater SRT scores due to a greater “cumulative” frequency of word usage than younger age groups. This may have contributed towards the positive developmental trajectory of SRTs demonstrated in this study.

Significant differences in mean SRTs were not present between adjacent age groups, but significant differences were present between age groups with at least a two-year difference. Significant differences were predominantly between the six-year old age group and remaining groups. Previous studies have shown a similar systematic improvement in speech recognition performance, in quiet and noise, as children mature to adolescence (Eisenberg et al., 2000; Ross et al., 2011). Ross et al. (2011) tested multisensory speech recognition abilities in typically developing children aged five to 14 years, finding that the ability to recognise auditory stimuli, in absence of other sensory modalities, modestly improved with increasing age. This improvement in speech recognition appears to occur at a slower rate than the initial speech and language development in a child’s first five years of life (Eisenberg et al., 2000).

4.2.2 Ear effect.

Potential for an ear effect, defined as the lateral difference in hearing threshold in absence of ear pathology, was investigated (Chung, Mason, Gannon, & Willson, 1983). Overall, there appeared to be no significant difference in SRT scores between the left and right ears. Many studies have shown a slightly greater acuity of the right ear than the left in adult populations, particularly in male individuals (Chung et al., 1983). In children aged five to 14 years, the University of Pittsburgh Graduate School of Public Health (1963) found

minimal differences in hearing thresholds between the left and right ears. It is possible that an ear effect may only develop from adolescence onwards as the brain continues to grow and mature.

Language is generally lateralised to the left hemisphere of the brain but can be found in the right, a lateralisation defined more so for right-handed than left-handed people (Isaacs, Barr, Nelson, & Devinsky, 2006). Dominance of crossed auditory pathways underlies greater right ear acuity, as verbal material arriving at the right ear is processed in the left cerebral hemisphere (Kimura, 1961). Cerebral dominance for language is linearly and significantly related to the individual's degree of handedness (Knecht et al., 2000). As no data on degree of handedness was collected in this study, SRT scores of left-handed and right-handed subgroups could not be explored separately. Therefore, a potential ear effect could not be ascertained with confidence.

Pairs of age groups showing significant differences in mean SRT scores were nonidentical between the left and right ears. For example, mean SRT scores produced with the left ear were significantly different for the 8 and 10-year-old age groups, but not significantly different for these same age groups when the UCAMST-P was run with the right ear. It is unclear why such differences were present, as no ear effect was discovered; the small sample size of each age group may have contributed towards the disparate findings.

4.2.3 Gender Effect.

Mean combined SRT scores were not significantly different between male and female participants across all age groups. No gender diverse individuals participated in this study. In the past, the biggest difference in hearing between male and female genders appeared to be in the aging process, as opposed to hearing ability itself (Jerger, Chmiel, Allen, & Wilson,

1994). For example, Jerger et al. (1994) investigated the effects of age and gender on dichotic sentence identification and found that age-related hearing issues were predominantly greater with the left ear than the right. This was more evident among male than female participants. There have been minimal findings on the effect of gender on an individual's ability to perceive speech at a single point in time, although a gender effect may influence the aging decline of speech recognition ability.

4.3 Co-variates

Data was collected on a child's household income, presence or non-presence of certain behavioural and developmental disorders, and the child's current and past achievement of reading, writing, language, and behaviour curriculum standards. None of these variables were found to influence SRT scores. The small sample size used in this study may have affected the accuracy with which the influence of these variables could be determined. As the main aim of this study was to create normative data, the majority of participants were typically-developing children. Thus, there were minimal numbers of children with behavioural or developmental disorders, or children not meeting curriculum standards, with which to compare. There was a lack of power to analyse significant differences in SRT between typically developing and non-typically developing children.

4.4 Study Limitations and Future Research

A number of limitations with the current research project affected the accuracy of normative data produced, and limited the analyses that could be run. These include the small sample size, multiple testers, and school testing conditions.

4.4.1 Sample size.

In total, 144 children took part in this study, divided into approximately twenty participants per age group. This is a small number on which to base normative data, making it difficult to distinguish outliers that could skew the data. Since a Master of Audiology thesis at the University of Canterbury is completed over a one-year period, it was not feasible to include a greater number of participants. It is recommended to test a higher number of participants in the future as this would increase the accuracy and validity of normative data for the UCAMST-P. In addition, it would increase the accuracy with which co-variables could be explored, as more participants could be included in each category.

4.4.2 Recruitment.

Participants were recruited from local primary schools and a study database, both based in Christchurch, producing data likely to be representative of normal-hearing individuals in Christchurch. However, the same sample may not be as representative of normal-hearing individuals across NZ. It is possible that the population within Christchurch may produce a set of results significantly different to populations within other areas, due to socioeconomic, ethnic, geographical, cultural, and linguistic differences, among others. It is advisable for sampling to be undertaken across NZ, or even to add data from another city, to add value to the normative data that is produced for the UCAMST-P.

4.4.3 Inter-tester reliability.

Administration of the UCAMST-P was completed in conjunction with another Master of Audiology student (Yau, in progress). Measures were taken to ensure minimal variability between each tester's administration of the UCAMST-P, such as practising administration of the UCAMST-P and outlining required steps of data collection together. Even so, there will always be inter-tester variability due to inherent individual differences. Having just one tester

collect data could remove inter-tester variability, but could magnify tester error. It is possible that assigning multiple testers to collect normative data may “wash out” the influence of inter-tester variability on results. Potentially, data could be collected this way in future studies on the UCAMST-P, but the feasibility of this depends on the resources available at that time.

4.4.4 School testing conditions.

Data collection of children recruited from the NZILBB database was carried out in acoustically-treated rooms. In contrast to this, children recruited directly from local schools were tested in a classroom at the school they attended. Requesting this cohort of participants to undergo testing at the University of Canterbury in sound-treated rooms was not reasonable, as it would have been demanding on the family’s time and resources.

At some schools, ambient noise levels were quite high due to children playing or learning immediately outside the testing classroom. As such, ambient noise may have affected the performance of children completing the UCAMST-P. It would be better in future to schedule testing sessions in periods in which classes were not expected immediately outside the classroom. Unfortunately, in this study it was difficult to schedule testing around a school’s timetable due to time constraints of the study. It may also be suitable to use a sound level meter in future to monitor ambient noise levels. This ensures noise does not exceed a specified threshold level while testing.

4.5 Future Research

A number of avenues could be explored when conducting future research with the UCAMST-P, and these are explored below. To further the development of the UCAMST-P and increase feasibility of its use in clinical settings, it is recommended to assess equivalence

of the new sentence lists generated in this study. Investigating the performance of children on the UCAMST-P in other conditions could increase the diagnostic information. For example, in: auditory-alone and closed-set conditions; with children with hearing impairment; and younger children with normal hearing. This could make the information gained from the UCAMST-P more practical in a clinical environment.

4.5.1 Sentence list equivalence.

New sentence lists for the UCAMST-P were generated in this study, with the aim of producing sentence lists with greater equivalence than that used previously (Jenkins-Foreman, 2018). Due to the SRT tracking procedure used in the current study of the UCAMST-P, equivalence of sentence lists could not be assessed with regards to slope. Sentence list equivalence can, however, be assessed with regards to SRT. Unfortunately, due to time constraints, it was not possible to investigate the mean SRT of each sentence list, and analyse any significant differences between each list in regards to this. A greatly reduced SD of mean SRTs attained previously for each sentence stimuli suggested a greater equivalence of the sentence lists used in this study than that previously (Jenkins-Foreman, 2018). It would add value to the development of the UCAMST-P if equivalence of the newly generated sentence lists were analysed in future.

4.5.2 Conditions in which UCAMST-P is administered.

In this study, the UCAMST-P was administered only in the auditory-alone, open-set condition to minimise the influence of visual speech cues and reading ability on test performance. It would be useful in future research to explore the performance of children in conditions other than just the auditory-alone, open-set condition. Administering the UCAMST-P in the audio-visual and closed-set conditions, and in different condition

combinations, could provide useful diagnostic information and assist in tailoring a rehabilitation plan to the listener (Tye-Murray et al., 2007).

4.5.3 Piloting with younger age groups.

A greater variability in development has been seen in younger age groups than older groups (Beahan et al., 2009; Holder et al., 2016; Neumann et al., 2012). It would be interesting to pilot the UCAMST-P with younger children, e. g. three to five-year-olds, to assess the viability of using the UCAMST-P with this population. This could also provide further information on a potential developmental trajectory of SRT scores across younger age groups.

4.5.4 Piloting with children with hearing impairment.

Prior research has shown greater difficulty perceiving speech in background noise in children with hearing impairment compared to those with normal hearing (Lewis et al., 2016; Ng et al., 2011). Conditions that negatively affect the audibility of speech signals, such as poor acoustics and HI, may result in a greater allocation of resources for bottom-up processing. Fewer resources for top-down processing are left, as there is a finite capacity of the brain to attend to sensory input (Lewis et al., 2016). This may explain the increased difficulty of children with HI to perceive speech in noisy conditions. Collecting data on the performance of children with HI on the UCAMST-P would add diagnostic value, as it would allow comparison of the range of results expected from those with HI and those with normal hearing.

4.6 Concluding Remarks

The UCAMST-P was developed with the intention of adding a reliable speech-in-noise test to the current paediatric audiological test battery. Age-related norms were needed

to allow future application of the test within the New Zealand clinical context. In addition, new sentence list stimuli needed to be generated to provide stimuli with less variability in SRT scores than that previously shown (Jenkins-Foreman, 2018). In this study, new sentence lists were generated with a lower variability in SRT scores, and SRTs were measured for children aged six to 12 years within Christchurch. Subsequent research with the UCAMST-P in different conditions and with different populations will assist in providing a speech-in-noise test that is applicable in both research and clinical contexts, and provide another avenue by which clinicians can address the impact of hearing impairment for each individual.

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Appendices

A. Ethical Approval

A.1 Ethical approval letter, The University of Canterbury Educational Research Human Ethics Committee.



HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: 2018/04/ERHEC

18 July 2018

Marie Lay and Justin Yau
Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Marie and Justin

Thank you for submitting your low risk application to the Educational Research Human Ethics Committee for your research proposal titled "Development of the University of Canterbury Paediatric Auditory-Visual Matrix Sentence Test: Sentence Equivalence and Normative Data *and* Normative Data for the UCAST-FW Test of APD in Children to Produce Correction Factors for Adjustment to Maturation Effect".


I am pleased to advise that this application has been reviewed and I confirm support of the School's approval for this project.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 26th June and 3rd July 2018.

With best wishes for your project.

Yours sincerely

PP


Dr Patrick Shepherd
Chair
Educational Research Human Ethics Committee

Please note that ethical approval relates only to the ethical elements of the relationship between the researcher, research participants and other stakeholders. The granting of approval by the Educational Research Human Ethics Committee should not be interpreted as comment on the methodology, legality, value or any other matters relating to this research.

F E S

**A.2 Amendment to ethical approval letter, The University of Canterbury
Educational Research Human Ethics Committee.**



HUMAN ETHICS COMMITTEE

Secretary
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: 2018/04/ERHEC-IR Amendment 1

25 September 2018

Marie Lay and Justin Yau
Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Marie and Justin

Thank you for your request for an amendment to your research proposal "Development of the University of Canterbury Paediatric Auditory-Visual Matrix Sentence Test: Sentence Equivalence and Normative Data and Normative Data for the UCAST-FW Test of APD in Children to Produce Correction Factors for Adjustment to Maturation Effect" as outlined in your email dated 20th September 2018. I am pleased to advise that this amendment has been considered and approved by the Educational Research Human Ethics Committee.

Please note that should circumstances relevant to this current application change you are required to reapply for ethical approval.

If you have any questions regarding this approval, please advise.

We wish you well for your continuing research.

Yours sincerely

PP Dr Patrick Shepherd
Chair
Educational Research Human Ethics Committee

Please note that ethical approval relates only to the ethical elements of the relationship between the researcher, research participants and other stakeholders. The granting of approval by the Educational Research Human Ethics Committee should not be interpreted as comment on the methodology, legality, value or any other matters relating to this research.

F E S

B. Information Documentation

B.1 Parent/Guardian Information Sheet for parents/guardians of participants recruited from primary schools and the “Learning to Talk” database (page 1 of 2).

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz

28/06/18
ERHEC Ref: 2018/04/ERHEC



Normative Data for the UCAMST-P and UCAST-FW Information Sheet for the Parent/Guardian

Principal Researchers:	Marie Lay and Justin Yau, MAud students (2 nd year) Department of Communication Disorders
Research Supervisor:	Associate Professor Greg O'Beirne Department of Communication Disorders
Associate Supervisors:	Dr. Rebecca Kelly-Campbell, Senior Lecturer Department of Communication Disorders Professor Suzanne Purdy, Head of School Psychology Department, University of Auckland

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects, and will gather information regarding the normal range of results we could expect in the general population.

You have been approached for your child to take part in this study because their school teacher has notified us that they are eligible to participate in this study, or they are part of the Team Tamariki database. I have located your contact details through your child's school administration database with prior approval from the principal of the school, or from Jayne Newbury, the co-director of the University of Canterbury Child Language Centre.

Testing will take place at the University of Canterbury (either in the Audiology clinics of the Department of Communication Disorders, or the Audiology laboratory in Rutherford 801) or the school the child attends (in a classroom set aside for testing).

To be eligible to participate, your child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

Prior to any testing, you will be given a short questionnaire focused on your child's ear health and family context. Your child's teacher will also be given a short questionnaire regarding their listening behaviour at school and their reading, writing, language, and behavioural development. Your child's ears will then be examined, and they will undergo a hearing check (if you have not provided an audiologist-completed audiogram dated within six months). Your child will be given a copy of their hearing screen to bring home which may include referral information for further diagnostic assessment if an unexpected hearing loss is found. If a hearing loss is found, a full audiological assessment will be offered at the University of Canterbury Speech and Hearing Clinic free of charge. If you choose to follow up with your GP or an external audiologist, this will be at your own expense.

Following the hearing check, your child will complete two sentence tests. In one test your child will hear short sentences being read aloud in noise. The words will change in loudness and may at times become difficult for your child to hear. After each sentence has been read, your child will be asked to repeat what they thought they heard. In the other test your child will hear words being read aloud without noise, but clarity of words will progressively worsen. After each word has been heard, your child will be asked to select one of four pictures on a tablet, corresponding to the word they think they heard. These two tests should take no more than 45 minutes in total. Breaks will be provided as needed, and testing may be spread over more than one session where appropriate.

There are no foreseeable risks to participants except for the risk of emotional distress any child may experience when consulting for normal hearing services. The procedures in this study are the same procedures a client would normally

B.1 Parent/Guardian Information Sheet for parents/guardians of participants

recruited from primary schools and the “Learning to Talk” database (page 2 of 2).

encounter in a hearing evaluation (i.e. there is no deviation from the normal clinic protocol used by the University of Canterbury other than presentation of the speech perception test and filtered words test).

Participation is voluntary and you and your child have the right to withdraw at any stage without penalty. You may ask for your child's raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you and your child. However, once analysis of raw data starts in approximately mid-August, it will become increasingly difficult to remove the influence of your child's data on the results.

All identifying information will be kept in secure facilities and in password protected electronic form and only viewed by people directly involved in this study (those listed below). Data will be safely kept for five years and then deleted from the server. Research data gathered in this study may be published and used in future studies but will not identify you and your child. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project and if you wish to be contacted for your child's participation in future research. This consent form is provided for you to sign on behalf of your child prior to their participation in this study. Your child will also be given an assent form to fill out prior to testing if they wish to be involved.

We are happy to answer any queries you may have. Our phone and email details are provided in case you have any questions either now or at a later date. As a token of our appreciation you will receive an honorarium of a \$10 voucher, as well as the hearing check for your child mentioned above.

This project is being carried out as a requirement of the Master of Audiology degree by Marie Lay and Justin Yau under the supervision of Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee, and participants should address any complaints to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return the consent form to your child's teacher before your child actively participates in this research.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
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Phone: 0277462856

Greg O'Beirne, PhD
Primary Research Supervisor & Associate Professor in Audiology
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Phone: +64 3 369 4313

Suzanne Purdy
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Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer in Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

B.2 Parent/Guardian Information Sheet for parents/guardians of participants

recruited from the “Dorayme Music Tuition Studio Ltd” music school (page 1 of 2).

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz

28/06/18
ERHEC Ref: 2018/04/ERHEC



Normative Data for the UCAMST-P and UCAST-FW Information Sheet for the Parent/Guardian

Principal Researchers: Marie Lay and Justin Yau, MAud students (2nd year)
Department of Communication Disorders

Research Supervisor: Associate Professor Greg O’Beirne
Department of Communication Disorders

Associate Supervisors: Dr. Rebecca Kelly-Campbell, Senior Lecturer
Department of Communication Disorders

Professor Suzanne Purdy, Head of School
Psychology Department, University of Auckland

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects, and will gather information regarding the normal range of results we could expect in the general population.

You have been approached for your child to take part in this study because their school or music teacher has notified us that they are eligible to participate in this study, or they are part of the Team Tamariki database. I have located your contact details through your child’s school administration database with prior approval from the principal of the school, from your music teacher at Dorayme Music Tuition Studio Ltd, or from Jayne Newbury, the co-director of the University of Canterbury Child Language Centre.

Testing will take place at the University of Canterbury (either in the Audiology clinics of the Department of Communication Disorders, or the Audiology laboratory in Rutherford 801), the Dorayme Music Tuition Studio Ltd teaching room, or the school the child attends (in a classroom set aside for testing).

To be eligible to participate, your child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

Prior to any testing, you will be given a short questionnaire focused on your child’s ear health and family context. Your child’s school teacher will also be given a short questionnaire regarding their listening behaviour at school and their reading, writing, language, and behavioural development. Your child’s ears will then be examined, and they will undergo a hearing check (if you have not provided an audiologist-completed audiogram dated within six months). Your child will be given a copy of their hearing screen to bring home which may include referral information for further diagnostic assessment if an unexpected hearing loss is found. If a hearing loss is found, a full audiological assessment will be offered at the University of Canterbury Speech and Hearing Clinic free of charge. If you choose to follow up with your GP or an external audiologist, this will be at your own expense.

Following the hearing check, your child will complete two sentence tests. In one test your child will hear short sentences being read aloud in noise. The words will change in loudness and may at times become difficult for your child to hear. After each sentence has been read, your child will be asked to repeat what they thought they heard. In the other test your child will hear words being read aloud without noise, but clarity of words will progressively worsen. After each word has been heard, your child will be asked to select one of four pictures on a tablet, corresponding to the word they think they heard. These two tests should take no more than 45 minutes in total. Breaks will be provided as needed, and testing may be spread over more than one session where appropriate.

There are no foreseeable risks to participants except for the risk of emotional distress any child may experience when

B.2 Parent/Guardian Information Sheet for parents/guardians of participants

recruited from the “Dorayne Music Tuition Studio Ltd” music school (page 2 of 2).

consulting for normal hearing services. The procedures in this study are the same procedures a client would normally encounter in a hearing evaluation (i.e. there is no deviation from the normal clinic protocol used by the University of Canterbury other than presentation of the speech perception test and filtered words test).

Participation is voluntary and you and your child have the right to withdraw at any stage without penalty. You may ask for your child's raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you and your child. However, once analysis of raw data starts in approximately mid-August, it will become increasingly difficult to remove the influence of your child's data on the results.

All identifying information will be kept in secure facilities and in password protected electronic form and only viewed by people directly involved in this study (those listed below). Data will be safely kept for five years and then deleted from the server. Research data gathered in this study may be published and used in future studies but will not identify you and your child. A thesis is a public document and will be available through the UC Library.

Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project and if you wish to be contacted for your child's participation in future research. This consent form is provided for you to sign on behalf of your child prior to their participation in this study. Your child will also be given an assent form to fill out prior to testing if they wish to be involved.

We are happy to answer any queries you may have. Our phone and email details are provided in case you have any questions either now or at a later date. As a token of our appreciation you will receive an honorarium of a \$10 voucher, as well as the hearing check for your child mentioned above.

This project is being carried out as a requirement of the Master of Audiology degree by Marie Lay and Justin Yau under the supervision of Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee, and participants should address any complaints to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return the consent form to your child's teacher, or one of the researchers, before your child actively participates in this research.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
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Greg O'Beirne, PhD
Primary Research Supervisor & Associate Professor in
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Suzanne Purdy
Secondary Research Supervisor & Head of School
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Rebecca Kelly-Campbell
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B.3 Information Sheet for six to 10-year-old participants.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



INFORMATION SHEET For 6-10 year olds



Marie and Justin are doing a project to find out how well children can play three different listening games. These games tell us how good a child's hearing is.



If I take part in this project,

- 1) We will look in your ears with a little torch
- 2) You will play 3 different listening games, with headphones on:

A close-up illustration of a hand with a red button being pressed.	Game 1: You will push a button when you hear a whistle sound.
A cartoon illustration of two children, a boy and a girl, standing and talking to each other.	Game 2: You will listen to short sentences, with some noise in the background. We will ask you to repeat what you heard.
A black iPad showing a home screen with various app icons.	Game 3: You will listen to words that might sound muffled. We will ask you to select the picture of the word on an iPad.



I can say no if I don't want to play these games. I can tell my parent or the person looking after me if I don't want to play. I can tell Marie or Justin or my teacher as well. I can change my mind later, even if I say yes now.



I can ask my teacher, parent, the person looking after me, Marie or Justin if I have any problems or questions.

My parent or the person looking after me knows I have been asked to be part of this study.

B.4 Information Sheet for 11 and 12-year-old participants.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



INFORMATION SHEET For 11-12 year olds

Why are we meeting with you?

We are doing a “research study”, which is when investigators collect information to learn more about something. Marie and Justin are trying to learn more about how well children can complete some listening games. After we tell you about our study, we will ask if you’d like to be in it or not. Your parent or the person taking care of you knows that we asked you to be part of this study.

Why are we doing this study?

We want to find out how well kids with good hearing can finish three different listening games. This study will help make the listening games better at testing how good a child’s hearing is.

What will you do in this study?

If you agree, we will ask you to complete these four things:

1. Marie or Justin will look in your ears with a little torch.
2. Game 1: You will wear headphones and listen for whistle sounds. We will ask you to push a button whenever you hear the whistle sounds.
3. Game 2: You will listen to short sentences, with noise playing. We will ask you to say to us what you hear.
4. Game 3: You will listen to words that might sound muffled. We will ask you to choose the picture of the word you heard on an iPad.



This should all take about 45 minutes.

Do I have to be in the study?

No, you don’t. No one will be mad at you if you say no. If you don’t want to be in this study, just tell us, or your parent, or the person who looks after you. If you do want to be in the study, tell us that. And, remember, you can say yes now and change your mind later. It’s up to you.

What if there is a problem?

If you are worried about the study or have any questions you can ask your parent or the person who looks after you. You can also ask Justin or Marie if you want to.



B.5 Teacher Information Sheet for school teachers of participants recruited from primary schools (page 1 of 2).

Department of Communication Disorders
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Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



29 June 2018
ERHEC Ref: 2018/04/ERHEC

Normative Data for the UCAMST-P and UCAST-FW Information Sheet for Schools and Teachers

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects, and will gather information regarding the normal range of results we could expect in the general population.

You have been approached to take part in this study because we would like children in your class to participate in our study. I have located your contact details via the school's principal. If you choose to take part in this study, your involvement in this project will involve emailing the parent/guardian information sheet and consent form to parents/guardians of children who meet the inclusion criteria and return completed consent forms to the researchers (contact information displayed on page 2).

To be eligible to participate, a child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

If you are unsure if a child meets the above inclusion criteria, we are happy for you to email the information sheet and consent form to the parent/guardian regardless. If a parent/guardian is unable to complete the written consent form but is happy for their child to participate, we ask that they sign the "verbal consent from the parent/guardian" section of the consent form, in lieu of the parent/guardian.

Prior to this investigation, you will also be asked to fill out a short questionnaire for each child from your class that agrees to participate. The questionnaire asks about the child's reading, writing, language, and behavioural development, and listening behavior in the classroom.

We would also appreciate if you allowed your students to participate during class time. Each participant will only be required to complete one assessment session of approximately 45 minutes duration. Examination of each child's ears will occur before they complete a hearing screen. They will then complete two sentence tests. The researchers will go through the appropriate information sheet and assent form with each participant prior to testing.

There are no foreseeable risks to participants except for the risk of emotional distress any child may experience when consulting for normal hearing services. The procedures in this study are the same procedures a client would normally encounter in a hearing evaluation (i.e. there is no deviation from the normal clinic protocol used by the University of Canterbury other than presentation of the speech perception test and filtered words test).

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for any information you have provided to be returned to you or destroyed at any point. If you withdraw, we will remove information relating to you. However, once data collection starts in Term 3 of the school year, it will become increasingly difficult to remove the influence of your data on the results.

Students will be given a copy of their hearing screen to take home to their parent/guardian. Any questions a

B.5 Teacher Information Sheet for school teachers of participants recruited from primary schools (page 2 of 2).



parent/guardian may have on their child's hearing screen results, or any other matters related to the study, can be directed to the researchers.

All identifying information will be kept in secure facilities and in password protected electronic form. Data will be safely kept for no less than five years and then deleted from the server. Research data gathered in this study may be published and used in future studies but will not identify the participants or the school they attended. A thesis is a public document and will be available through the UC Library.

The project is being carried out as a requirement of the Master of Audiology degree by Marie Lay and Justin Yau under the supervision of Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee, and participants should address any complaints to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return to either Marie Lay, who can be contacted on marie.lay@pg.canterbury.ac.nz, or Justin Yau, who can be contacted on justin.yau@pg.canterbury.ac.nz. Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project. You may also contact us at any time (before, during, or after the study) if you have any questions or concerns.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
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Justin Yau
2nd year MAud Student
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Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer
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Greg O'Beirne, PhD
Primary Research Supervisor & Associate
Professor in Audiology
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B.6 Teacher Information Sheet for school teachers of participants recruited from the NZILBB “Learning to Talk” study database and the “Dorayme Music Tuition Studio Ltd” music school (page 1 of 2).

Department of Communication Disorders
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www.cmds.canterbury.ac.nz



29 June 2018
ERHEC Ref: 2018/04/ERHEC

Normative Data for the UCAMST-P and UCAST-FW Information Sheet for Teachers

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects, and will gather information regarding the normal range of results we could expect in the general population.

You have been approached to take part in this study because a child from your class has chosen to participate in our study. I have located your contact details via the child's parent/guardian. If you choose to take part in this study, your involvement in this project will involve completing a short questionnaire about the child's reading, writing, language, and behavioural development, and listening behavior in the classroom.

Each participant will complete one assessment session of approximately 45 minutes duration. Examination of each child's ears will occur before they complete a hearing screen. They will then complete two sentence tests. The researchers will go through the appropriate information sheet and assent form with each participant prior to testing.

There are no foreseeable risks to participants except for the risk of emotional distress any child may experience when consulting for normal hearing services. The procedures in this study are the same procedures a client would normally encounter in a hearing evaluation (i.e. there is no deviation from the normal clinic protocol used by the University of Canterbury other than presentation of the speech perception test and filtered words test).

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for any information you have provided to be returned to you or destroyed at any point. If you withdraw, we will remove information relating to you. However, once data collection starts in Term 3 of the school year, it will become increasingly difficult to remove the influence of your data on the results.

Students will be given a copy of their hearing screen to take home to their parent/guardian. Any questions a parent/guardian may have on their child's hearing screen results, or any other matters related to the study, can be directed to the researchers.

All identifying information will be kept in secure facilities and in password protected electronic form. Data will be safely kept for no less than five years and then deleted from the server. Research data gathered in this study may be published and used in future studies but will not identify the participants or the school they attended. A thesis is a public document and will be available through the UC Library.

The project is being carried out as a requirement of the Master of Audiology degree by Marie Lay and Justin Yau under the supervision of Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee, and participants should address any complaints to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch ([human-](#)

B.6 Teacher Information Sheet for school teachers of participants recruited from the NZILBB “Learning to Talk” study database and the “Dorayme Music Tuition Studio Ltd” music school (page 2 of 2).



ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return to either Marie Lay, who can be contacted on marie.lay@pg.canterbury.ac.nz, or Justin Yau, who can be contacted on justin.yau@pg.canterbury.ac.nz. Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project. You may also contact us at any time (before, during, or after the study) if you have any questions or concerns.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
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Phone: 0277462856

Greg O'Beirne, PhD
Primary Research Supervisor & Associate
Professor in Audiology
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Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
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Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer
in Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

B.7 Teacher Information Sheet for music teachers of participants recruited from the “Dorayne Music Tuition Studio Ltd” music school (page 1 of 2).

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.beisett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



29 June 2018
ERHEC Ref: 2018/04/ERHEC

Normative Data for the UCAMST-P and UCAST-FW Information Sheet for Schools and Teachers

This study is part of two projects; one project aims to further develop a paediatric speech test in New Zealand English to supplement other tests typically used to assess hearing, and the other aims to further develop an auditory processing speech test to supplement tests currently used to diagnose auditory processing disorder (APD). This study is being carried out as part of two Master of Audiology thesis projects, and will gather information regarding the normal range of results we could expect in the general population.

You have been approached to take part in this study because we would like children from your music school to participate in our study. I have located your contact details via the school's principal. If you choose to take part in this study, your involvement in this project will involve emailing the parent/guardian information sheet and consent form to parents/guardians of children who meet the inclusion criteria and return completed consent forms to the researchers (contact information displayed on page 2).

To be eligible to participate, a child must:

- be 6 - 12 years of age
- have normal hearing
- have no current middle ear pathology (i.e. ear infections or surgeries)
- have no history of neurological disease or impairment

If you are unsure if a child meets the above inclusion criteria, we are happy for you to email the information sheet and consent form to the parent/guardian regardless. If a parent/guardian is unable to complete the written consent form but is happy for their child to participate, we ask that the you sign the “verbal consent from the parent/guardian” section of the consent form, in lieu of the parent/guardian.

We would also appreciate if you allowed your students to participate in one of the teaching rooms at the music studio. Each participant will only be required to complete one assessment session of approximately 45 minutes duration. Examination of each child's ears will occur before they complete a hearing screen. They will then complete two sentence tests. The researchers will go through the appropriate information sheet and assent form with each participant prior to testing.

There are no foreseeable risks to participants except for the risk of emotional distress any child may experience when consulting for normal hearing services. The procedures in this study are the same procedures a client would normally encounter in a hearing evaluation (i.e. there is no deviation from the normal clinic protocol used by the University of Canterbury other than presentation of the speech perception test and filtered words test).

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for any information you have provided to be returned to you or destroyed at any point. If you withdraw, we will remove information relating to you. However, once data collection starts, it will become increasingly difficult to remove the influence of your data on the results.

Students will be given a copy of their hearing screen to take home to their parent/guardian. Any questions a parent/guardian may have on their child's hearing screen results, or any other matters related to the study, can be directed to the researchers.

B.7 Teacher Information Sheet for music teachers of participants recruited from the “Dorayme Music Tuition Studio Ltd” music school (page 2 of 2).



All identifying information will be kept in secure facilities and in password protected electronic form. Data will be safely kept for no less than five years and then deleted from the server. Research data gathered in this study may be published and used in future studies but will not identify the participants or the music school they attended. A thesis is a public document and will be available through the UC Library.

The project is being carried out as a requirement of the Master of Audiology degree by Marie Lay and Justin Yau under the supervision of Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz. He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Educational Research Human Ethics Committee, and participants should address any complaints to The Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return to either Marie Lay, who can be contacted on marie.lay@pg.canterbury.ac.nz, or Justin Yau, who can be contacted on justin.yau@pg.canterbury.ac.nz. Please indicate to the researcher on the consent form if you would like to receive a copy of the summary of results of the project. You may also contact us at any time (before, during, or after the study) if you have any questions or concerns.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: jjy26@uclive.ac.nz
Phone: 0277462856

Greg O'Beirne, PhD
Primary Research Supervisor & Associate
Professor in Audiology
Department of Communication Disorders
University of Canterbury
Email: gregory.obeirne@canterbury.ac.nz
Phone: +64 3 369 4313

Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
Email: sc.purdy@auckland.ac.nz
Phone: +64 9 923 2073

Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer
in Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

C. Consent Forms

C.1 Parent/Guardian Consent Form (page 1 of 2).

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



Normative Data for the UCAMST-P and UCAST-FW Consent Form for the Parent/Guardian

- ☐ I have been given a full explanation of this project and have read and understand the Information Sheet and Parent Consent Form by which I will also receive a copy to keep.
- ☐ I understand I have the opportunity to ask questions at any time.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I agree that research data gathered in this study may be published and used in future studies. I provide consent for this publication and the re-use of the data with the understanding that my child's and my name or other identifying information will not be used.
- ☐ I understand that my child's participation in this project is voluntary and that they are free to withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information we have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and supervisors directly involved in the study as stated on page 2 of the information sheet and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.
- ☐ I understand the risks associated with taking part and how they will be managed pertaining to the procedures in the unlikely event that I may receive referral for further diagnostic assessment if an unexpected hearing loss is found.
- ☐ I understand that I can contact the researchers Marie Lay (marie.lay@pg.canterbury.ac.nz) or Justin Yau (justin.yau@pg.canterbury.ac.nz). Alternatively I may contact the supervisor Greg O'Beirne, who can be contacted at gregory.obeirne@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Educational Research Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)

I would like a summary of the results of the project (please tick one): **Yes** ☐ **No** ☐

I agree to be contacted in future, for my child's participation in ongoing research (please tick one): **Yes** ☐ **No** ☐

If yes to either of the above two options, please provide a contact email and/or postal address below:

.....

By signing below, I give consent for my child to participate in this research project.

Child's Name (please print): _____

Parent/Guardian Name: _____

Signed: _____ **Date:** _____

OR (please see next page)

C.1 Parent/Guardian Consent Form (page 2 of 2).

I have gained verbal consent from the child's parent/guardian to participate in this research project.

Child's Name (please print): _____

Parent/Guardian Name (please print): _____

Teacher's Name: _____

Signed: _____ **Date:** _____

Note: All parties signing the Consent Form must date their own signature. Please return the consent form to your child's teacher before your child actively participates in this research.

With thanks,

Marie Lay
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: msl55@uclive.ac.nz
Phone: 021 029 68881

Justin Yau
2nd year MAud Student
Department of Communication Disorders
University of Canterbury
Email: jjy26@uclive.ac.nz
Phone: 0277462856

Greg O'Beirne, PhD
Primary Research Supervisor & Associate
Professor in Audiology
Department of Communication Disorders
University of Canterbury
Email: gregory.obeirne@canterbury.ac.nz
Phone: +64 3 369 4313

Suzanne Purdy
Secondary Research Supervisor & Head of School
Psychology
The University of Auckland
Email: sc.purdy@auckland.ac.nz
Phone: +64 9 923 2073

Rebecca Kelly-Campbell
Secondary Research Supervisor & Senior Lecturer
in Audiology
Department of Communication Disorders
University of Canterbury
Email: rebecca.kelly@canterbury.ac.nz
Phone: +64 3 369 4519

C.2 Teacher Consent Form.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



Normative Data for the UCAMST-P and UCAST-FW Consent Form for Teachers

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and project supervisors and that any published or reported results will not identify the participants or the school they attend. I agree that research data gathered in this study may be published and used in future studies. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I can contact the researchers Marie (marie.lay@pg.canterbury.ac.nz) or Justin (justin.yau@pg.canterbury.ac.nz), or their supervisor Greg O'Beirne (gregory.obeirne@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Educational Research Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)
- ☐ I would like a summary of the results of the project.
- ☐ I understand that this project has been reviewed **and approved** by the University of Canterbury Educational Research Human Ethics Committee.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address (for report of findings, if applicable): _____

The consent form may be returned via email to the researchers: Marie Lay at marie.lay@pg.canterbury.ac.nz, or Justin Yau at justin.yau@pg.canterbury.ac.nz

D. Assent Forms

D.1 Assent Form for six to 10-year-old participants.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.cmds.canterbury.ac.nz



ASSENT FORM For 6-10 year olds

Marie and Justin's project about listening games has been explained to me. I know if I agree, Marie or Justin will look in my ears, and I will play three different listening games. I know I don't have to be part of it if I don't want to. I know that if I change my mind about playing the games, I can stop anytime I want to.

If I have any questions I can ask my teacher, mum, dad, or the person looking after me. I can also ask Marie or Justin.



I am happy for Marie or Justin to look in my ears and play the listening games, so I have coloured in the happy face.



I don't want Marie or Justin to look in my ears or play the listening games, so I have coloured in the sad face.

My full name:

Please give this back to your teacher now.



D.2 Assent Form for 11 and 12-year-old participants.



ASSENT FORM For 11-12 year olds



Participant's Name: _____
(Full Name in BLOCK CAPITALS)

Date of Birth: _____
(Month/Year)

Please circle all you agree with:

Have you read this form (or had it read to you)?	Yes/No
Has the investigator explained this study to you?	Yes/No
Do you understand what this study is about?	Yes/No
Have you asked all the questions you want?	Yes/No
Are you happy to take part in this research study?	Yes/No

If any answers are “**no**” or you **don’t** want to take part, **don’t** sign your name!

If you **do** want to take part in this study, please write your name and today’s date below.

You will be given a copy of this signed form.

Participant’s Full Name: _____

Participant’s Signature for Assent: _____

Date: _____

Statement of Person Obtaining Informed Assent

I, the undersigned, have fully explained the details of this research study to the participant named above.

Name

Signature

Date



E. Questionnaires

E.1 Parent/Guardian Questionnaire.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: fiona.bellett@canterbury.ac.nz
www.omds.canterbury.ac.nz



Parent/Guardian Questionnaire

1. Please circle your child's gender Male / Female / Gender Diverse (please specify): _____
2. What is your child's date of birth? (dd/mm/yyyy): _____
3. What is your child's ethnicity? (✓ as many as applicable)
☐ European ☐ Cook Island Māori ☐ Tongan ☐ Chinese ☐ Indian
☐ Māori ☐ Samoan ☐ Niuean ☐ Other (e.g. Dutch, Japanese): _____
4. Is English your child's first language? (please circle one) **Yes/No**
If not, when did they start learning English? _____
5. Does your child speak any other languages? (please circle one) **Yes/No**
If yes, please fill in the following (for proficiency, please circle one)
Language: _____ Years spoken: _____ Proficiency: Beginner / Intermediate / Advanced
Language: _____ Years spoken: _____ Proficiency: Beginner / Intermediate / Advanced
6. Please ✓ any of the following conditions or services experienced by your child
 - a. ____ Attention deficit disorder/ADHD
 - b. ____ Auditory processing disorder (C-APD)
 - c. ____ Autism/Asperger syndrome
 - d. ____ Chronic middle ear infections or surgery
 - e. ____ Developmental delay
 - f. ____ Dyslexia (or language learning disability ____)
 - g. ____ History of speech-language delay or therapy
 - h. ____ Jaundice as newborn: (a) Mild ____ (b) Moderate ____ (c) Severe ____
 - i. ____ Learning disability
 - j. ____ Learning English as a 2nd language after age 5
 - k. ____ Permanent hearing loss:
(a) Mild ____ (b) Moderate ____ (c) Severe ____ (d) Unilateral ____
(e) Hearing aid ____ (Left/Right/Both) (f) Cochlear implant ____ (Left/Right/Both)
 - l. ____ Special education
 - m. ____ NONE OF THESE
7. Please indicate the total income of your child's household below
\$ _____ ☐ Prefer not to say



Participant ID: _____

E.2 Teacher Questionnaire.

Department of Communication Disorders
Phone: +64 3 369 4827
Email: jana.baker@canterbury.ac.nz
www.smd.canterbury.ac.nz



Teacher Questionnaire

1. Is the child currently at or above the expected level for their age for the following (Yes/No):

Reading _____ Writing _____
Language _____ Behaviour _____

2. In the past, has the child been below the expected level for their age for the following (Yes/No):

Reading _____ Writing _____
Language _____ Behaviour _____

3. Teacher Evaluation of Auditory Performance (TEAP)

Please rate this child's behaviour compared to other children of similar age and background.

SECTION A. RESPONSE CHOICES

Less difficulty.....	+1
Same amount of difficulty	0
Slightly more difficulty	-1
More difficulty	-2
Considerably more difficulty	-3
Significantly more difficulty	-4
Cannot function at all.....	-5

If listening in a room where there is background noise such as others talking, children playing etc., this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

If listening in a quiet room (others may be present, but are being quiet), this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

When listening in ideal conditions (quiet room, no distractions, face-to-face, good eye contact), this child has difficulty hearing and understanding..... +1 0 -1 -2 -3 -4 -5

This child has difficulty following multistage oral instructions +1 0 -1 -2 -3 -4 -5

SECTION B. Please circle YES or NO

This child appears to have trouble picking up new spoken information and may require several repetitions in order to understand the material.....YES / NO

This child frequently requires visual cues to help understand the curriculum, in addition to auditory information.....YES / NO

This child has difficulty recalling auditory information, compared to other children.....YES / NO

This child displays difficulty formulating or generating expressive language, and/or displays inappropriate use of language.....YES / NO

If YES, please explain:

The child displays language problems (evidenced in the usage of inappropriate "wh" questions, pronouns, word order, possessiveness, verb tenses)YES / NO

If YES, please explain:

This child displays problems with articulation (phonology) consisting of substitutions, distortions, or omissions of sound in words (especially when producing words that sound similar)YES / NO

If YES, please explain:

Participant ID:

F. Sentence Lists

F.1 Sentence lists generated for use in the current study, with corresponding mean SRT \pm SD of each sentence and sentence list.

Revised List 01	SRT	Revised List 02	SRT	Revised List 03	SRT	Revised List 04	SRT
three new shoes	-5.58	eight green hats	-5.82	twelve red shoes	-5.56	ten red hats	-5.28
ten green toys	-5.84	ten small toys	-5.89	ten new toys	-6.00	nine new bikes	-5.46
ten new hats	-5.90	two red bikes	-5.98	three small shoes	-6.17	two new shoes	-5.90
three green books	-6.08	nine red shoes	-6.08	nine small hats	-6.44	nine green shoes	-6.06
two small books	-6.08	twelve old bikes	-6.21	nine green toys	-6.47	twelve green spoons	-6.06
nine old hats	-6.26	two new spoons	-6.37	two big books	-6.47	two small spoons	-6.08
two red toys	-6.40	twelve green shoes	-6.45	twelve old spoons	-6.71	eight old bikes	-6.42
nine big bikes	-6.61	nine old toys	-6.56	eight red spoons	-6.71	eight red toys	-6.42
eight old toys	-6.68	three red spoons	-6.70	ten old shoes	-7.18	three small hats	-6.60
twelve red bikes	-6.97	eight new shoes	-7.00	eight new bikes	-7.39	ten big books	-6.62
-6.2 \pm 0.4		-6.3 \pm 0.4		-6.5 \pm 0.5		-6.1 \pm 0.5	
Revised List 05	SRT	Revised List 06	SRT	Revised List 07	SRT	Revised List 08	SRT
eight big bikes	-5.60	two red books	-5.65	eight big books	-5.39	ten big shoes	-5.09
nine new hats	-5.89	ten small hats	-5.98	ten new shoes	-5.85	three new bikes	-5.44
eight new toys	-6.05	twelve big books	-6.04	two red hats	-5.97	twelve small toys	-5.78
ten old books	-6.06	eight green toys	-6.24	twelve small hats	-6.00	three green toys	-5.81
twelve small spoons	-6.22	nine new spoons	-6.28	nine green spoons	-6.02	nine red bikes	-5.85
ten red toys	-6.58	twelve new shoes	-6.34	two old shoes	-6.65	eight green shoes	-6.08
three red hats	-6.70	ten red books	-6.57	twelve green toys	-7.14	ten old hats	-6.41
twelve green books	-6.78	twelve old toys	-6.57	nine new toys	-7.26	three old books	-6.66
two green bikes	-7.04	three small spoons	-7.13	ten old spoons	-7.38	twelve new books	-6.77
three old shoes	-7.07	eight red bikes	-7.56	three red toys	-7.38	nine red spoons	-7.96
-6.4 \pm 0.5		-6.4 \pm 0.6		-6.5 \pm 0.7		-6.2 \pm 0.8	
Revised List 09	SRT	Revised List 10	SRT	Revised List 11	SRT	Revised List 12	SRT
twelve new spoons	-5.13	two green toys	-5.04	twelve new hats	-5.35	two small hats	-5.02
nine green hats	-5.15	three green hats	-5.96	three small bikes	-5.39	ten green shoes	-5.05
two small bikes	-5.24	nine new books	-6.08	twelve green hats	-5.55	three red bikes	-5.17
twelve old hats	-5.82	three big books	-6.08	twelve big toys	-5.72	eight old shoes	-5.46
two red spoons	-6.27	eight small hats	-6.34	ten new spoons	-5.75	nine old spoons	-5.98
three new spoons	-6.57	twelve green bikes	-6.64	nine red hats	-5.98	three small books	-6.10
eight red books	-6.71	ten red spoons	-7.05	nine big books	-6.19	ten big toys	-6.32
three big toys	-6.75	nine old shoes	-7.13	eight old spoons	-6.60	nine red books	-6.98
eight new books	-6.96	two old spoons	-7.26	two old bikes	-7.18	twelve old shoes	-7.13
ten red shoes	-7.35	twelve new toys	-7.47	eight red shoes	-8.21	twelve red toys	-7.38
-6.2 \pm 0.8		-6.5 \pm 0.8		-6.2 \pm 0.9		-6.1 \pm 0.9	

G. Hearing Screen Result Sheets

G.1 Hearing screen result sheet for a passed hearing screen.

Department of Communication Disorders
Speech and Hearing Clinic
Ilam
Christchurch 8042



Date: _____

Tēnā koe: _____

_____ was seen for a hearing screen as part of the *Normative Data for the UCAMST-P* and *Normative Data for the UCAST-FW* studies.

PURE TONE AUDIOMETRY

This audiological screen identifies potential hearing loss whereby a small probe was placed in each ear to assess hearing. Adequate hearing is important for learning speech sounds and general listening skills in the class room.

Frequency	Right Ear	Left Ear
500 Hz		
1000 Hz		
2000 Hz		
4000 Hz		

TYMPANOMETRY

Right Ear: _____ Left Ear: _____

Key:

A	Eardrum moving well.
B	Eardrum not moving well. B _{low} : May indicate occluding wax, or fluid behind eardrum which happens with congestion i.e. cold/flu (could still be present before/after sickness). B _{high} : May indicate ruptured eardrum, or grommet in situ.
C	Eardrum moving well but sucked back a little. May indicate cold/flu (could still be present before/after sickness).

OTOSCOPY

Looking in the ears, with a small torch.

Right	Left

Result: **Pass – adequate hearing indicated, no follow-up recommended.**

If you have any questions about these results, feel free to contact me on marie.lay@pg.canterbury.ac.nz or 02102968881.

Ngā mihi nui,

Marie Lay
Masters of Audiology Student
University of Canterbury

G.2 Hearing screen result sheet for a hearing screen requiring referral for full audiological assessment.

Department of Communication Disorders
Speech and Hearing Clinic
Ilam
Christchurch 8042



Date: _____

Tēnā koe: _____

_____ was seen for a hearing screen as part of the *Normative Data for the UCAMST-P* and *Normative Data for the UCAST-FW* studies.

PURE TONE AUDIOMETRY

This audiological screen identifies potential hearing loss whereby a small probe was placed in each ear to assess hearing. Adequate hearing is important for learning speech sounds and general listening skills in the class room.

Frequency	Right Ear	Left Ear
500 Hz		
1000 Hz		
2000 Hz		
4000 Hz		

TYMPANOMETRY

Right Ear: _____ Left Ear: _____

Key:

A	Eardrum moving well.
B	Eardrum not moving well. B _{low} : May indicate occluding wax, or fluid behind eardrum which happens with congestion i.e. cold/flu (could still be present before/after sickness). B _{high} : May indicate ruptured eardrum, or grommet in situ.
C	Eardrum moving well but sucked back a little. May indicate cold/flu (could still be present before/after sickness).

OTOSCOPY

Looking in the ears, with a small torch.

Right	Left

Result: **Refer – further action recommended.**

This result indicates we could not gain a response within the range of normal hearing for the frequencies with an “x” above.

A full hearing assessment is recommended given this result. You may call the University of Canterbury Speech and Hearing Clinic to book in for a free hearing assessment on (03) 369 4827 or you can ask your GP to refer you for a hearing assessment via the hospital.

If you have any questions about these results, feel free to contact me on marie.lay@pg.canterbury.ac.nz or 02102968881.

Ngā mihi nui,

Marie Lay
Masters of Audiology Student
University of Canterbury